

Zan Merrill - ahm2452 - HW4

academic disclaimer: I used chatGPT in parts of this to assist in code clarity and better understanding of topics.

MIS 382N: Advanced Machine Learning Assignment 4

Total points: 55 pts

Due: 11:59 PM CST, Tuesday, November 4th, 2025.

Submission:

1. Submit your **Jupyter Notebook via Canvas**, AND
2. **Save your Jupyter Notebook to a PDF, and submit the PDF via Gradescope.**

You may work in groups of two if you wish. Only one student per team needs to submit the assignment on Canvas and Gradescope. But be sure to include the name and UT EID for both students.

Homework groups will be created and managed through Canvas, so please do not arbitrarily change your homework group. If you do change, let the TAs know.

For questions involving mathematical derivations, you can write your answer on paper and then upload an image. Also, please make sure your code runs and the graphics (and anything else) are displayed in your notebook before submitting.
(%matplotlib inline)

Name(s) and EID(s):

Bookmarks:

Q1. [Dimensionality Reduction - tSNE](#)

Q2. [Classification With a Loss Matrix](#)

Q3. [Visualizing the Confusion Matrices, ROC Curves, and PR Curves](#)

Q4. [Concepts about AU-ROC and AU-PRC](#)

Q1. Dimensionality Reduction - tSNE (15 pts)

In this problem, you will apply Principal Component Analysis (PCA) to the Superconductivity Dataset. More details about the dataset are available [here](#). The goal of this exercise is to characterize the structure of the input feature space.

Let's start with the following steps to prepare the dataset:

1. Load the dataset from the file `Q1_data.csv` into a pandas DataFrame named `df`.
2. The dataset contains a column called `critical_temp`, representing the critical temperature of each superconductor. Please select the column `critical_temp` as `y`. **We will not use this column when fitting t-SNE. However, you may retain it later for visualization (e.g., coloring points by `y`).**
3. Define the feature matrix: select all remaining columns (except `critical_temp`) from `df` as `X`.
4. Standardize the features using [Standard Scaling](#): Fit the scaler on `X`, and then transform `X` to obtain the standardized data. Apply scaling only to `X`, not to `y`.

Note: After this step, `X` should contain 81 features.

```
In [1]: q1_path = "https://raw.githubusercontent.com/AHMerrill/ml-4/main/Q1_data.csv"
        churn_path = "https://raw.githubusercontent.com/AHMerrill/ml-4/main/customer_churn_telcom.csv"
```

```
In [2]: ## Only use this code block if you are using Google Colab.
        ## If you are using Jupyter Notebook, please ignore this code block. You can directly upload the file to ,
        ## from google.colab import files

        ### It will prompt you to select a local file. Click on "Choose Files" then select and upload the file.
        ### Wait for the file to be 100% uploaded. You should see the name of the file once Colab has uploaded it
        ## uploaded = files.upload()
```

```
In [3]: from sklearn.linear_model import LinearRegression
        from sklearn.model_selection import train_test_split
```

```

from sklearn.feature_selection import SequentialFeatureSelector
import os, sys, re
import time
import numpy as np
import pandas as pd
from sklearn.preprocessing import MinMaxScaler, StandardScaler
import matplotlib.pyplot as plt

df = pd.read_csv(q1_path)

```

In [4]: `df.head(3)`

Out[4]:

	number_of_elements	mean_atomic_mass	wtd_mean_atomic_mass	gmean_atomic_mass	wtd_gmean_atomic_mass	e
0	4	88.944468	57.862692	66.361592	36.116612	
1	5	92.729214	58.518416	73.132787	36.396602	
2	4	88.944468	57.885242	66.361592	36.122509	

3 rows × 82 columns

In [5]:

```

y = df["critical_temp"]
X = df.drop(columns=["critical_temp"])

scaler = StandardScaler()
scaler.fit(X)
X = scaler.transform(X)

```

In [6]: `X.shape`

Out[6]: (21263, 81)

Part 1. (5 points) Now apply T-SNE to the dataset. You are required to carry out the following tasks:

1. Initialize a t-SNE model with number of dimensions = 3, perplexity = 300, number of iterations = 300 and random state = 42.
2. Apply the t-SNE model to the data.

Answer:

note: here we're assuming the entire q1_data is the training data. If a further test / train split is desired, it should be applied BEFORE the standard scaler

```
In [7]: from sklearn.manifold import TSNE

#### START CODE ####
## Initialize t-SNE with: n_components=3, perplexity=300, n_iter=300, random_state=42
tsne = TSNE(n_components=3, perplexity=300, n_iter=300, random_state=42)
#### END CODE ####

#### START CODE ####
## Apply t-SNE to the training dataset
X_tsne = tsne.fit_transform(X)
#### END CODE ####
```

Part 2. (5 points) Sample 1000 random data points from the dataset, and show the 2D scatter plots of their first three t-SNE components.

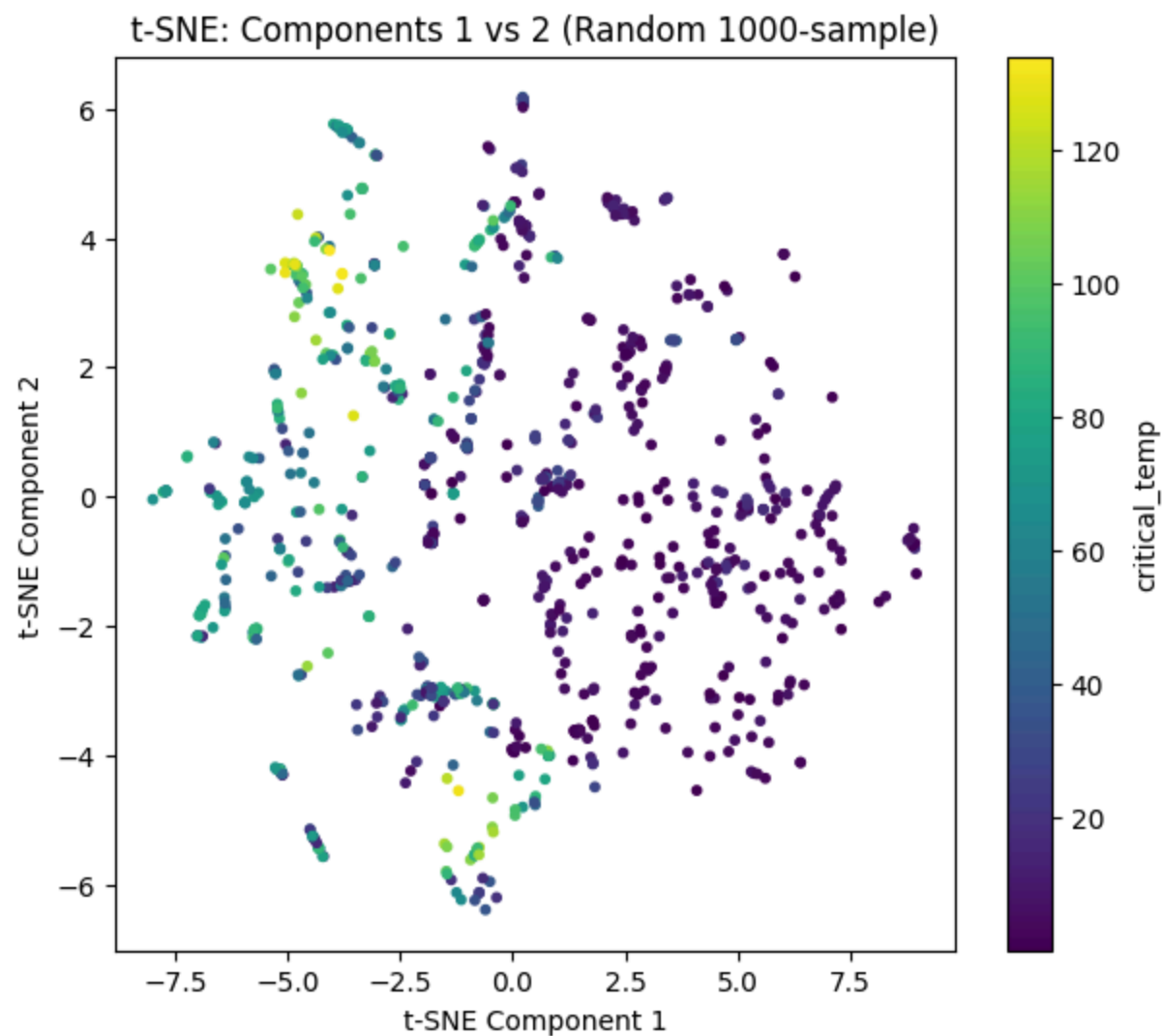
Answer:

```
In [8]: #### START CODE ####
# Sample 1000 random data points from the dataset
# Plot first two components (2D scatter)
# Hint: Use X_tsne[:1000, 0] and X_tsne[:1000, 1] as x/y axes.
# Color by y

# Sample 1000 random data points from the dataset
# did not follow the hint here because the hint is not a random sample...
sample_idx = np.random.choice(len(X_tsne), size=1000, replace=False)
X_sample = X_tsne[sample_idx]
y_sample = y.iloc[sample_idx]

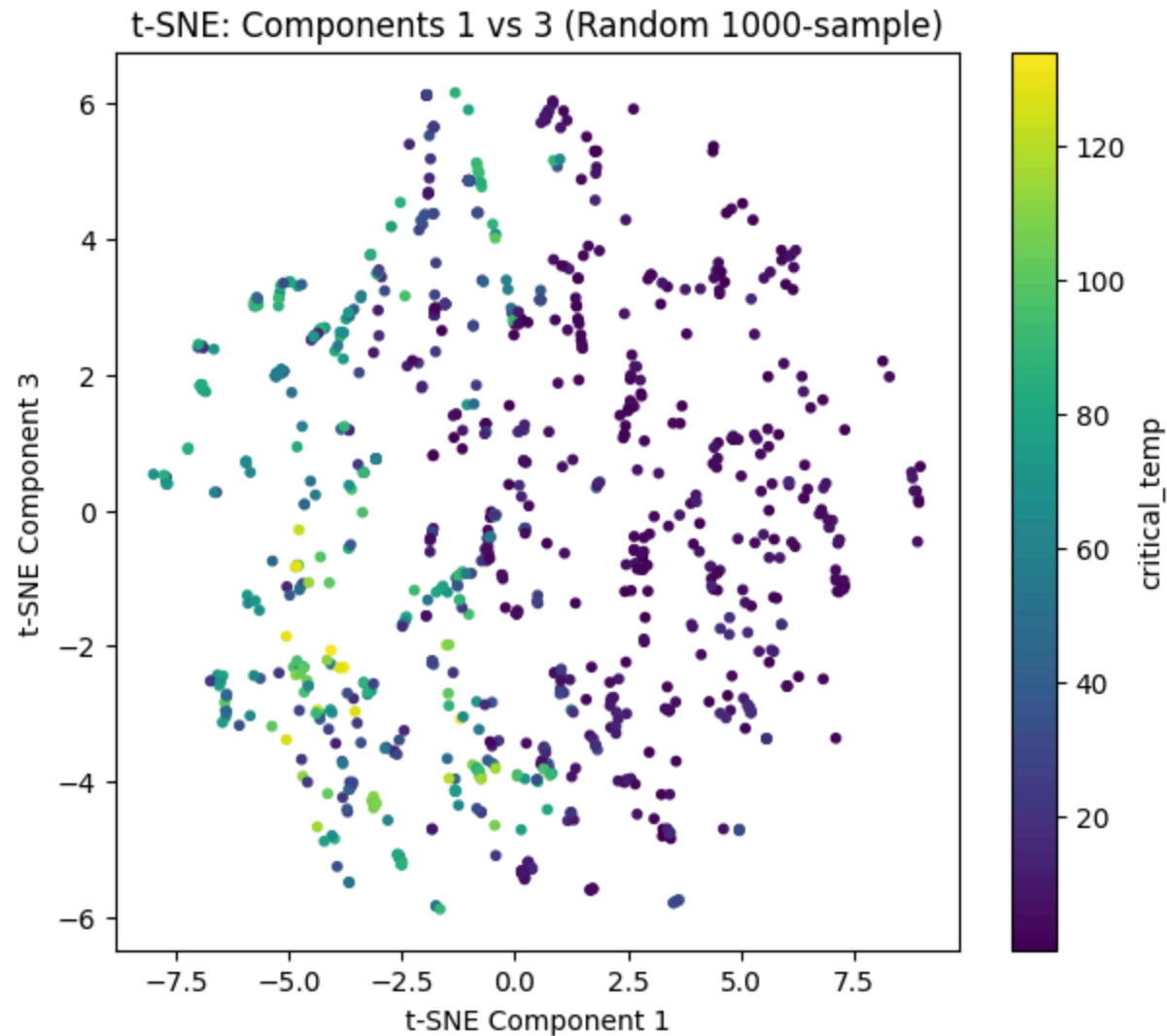
# Plot first two components (2D scatter)
plt.figure(figsize=(7,6))
plt.scatter(X_sample[:, 0], X_sample[:, 1], c=y_sample, cmap='viridis', s=10)
plt.colorbar(label="critical_temp")
plt.xlabel("t-SNE Component 1")
plt.ylabel("t-SNE Component 2")
plt.title("t-SNE: Components 1 vs 2 (Random 1000-sample)")
```

```
plt.show()  
### END CODE ###
```



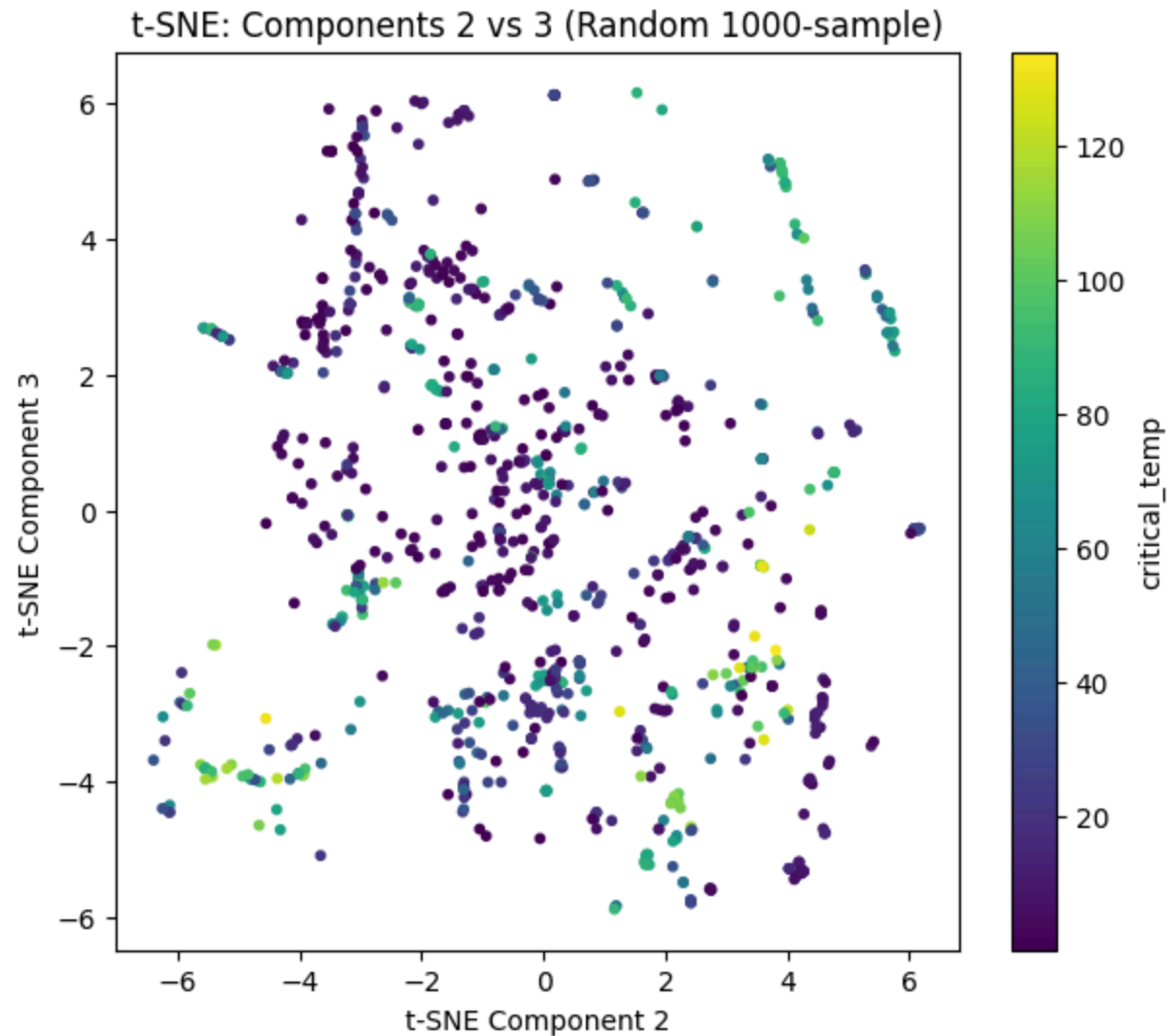
```
In [9]: ### START CODE ###  
# Plot the first and the third components (2D scatter)  
plt.figure(figsize=(7,6))  
plt.scatter(X_sample[:, 0], X_sample[:, 2], c=y_sample, cmap='viridis', s=10)  
plt.colorbar(label="critical_temp")  
plt.xlabel("t-SNE Component 1")
```

```
plt.ylabel("t-SNE Component 3")  
plt.title("t-SNE: Components 1 vs 3 (Random 1000-sample)")  
plt.show()  
### END CODE ###
```



```
In [10]: ### START CODE ###  
# Plot the second and the third components (2D scatter)  
plt.figure(figsize=(7,6))  
plt.scatter(X_sample[:, 1], X_sample[:, 2], c=y_sample, cmap='viridis', s=10)
```

```
plt.colorbar(label="critical_temp")
plt.xlabel("t-SNE Component 2")
plt.ylabel("t-SNE Component 3")
plt.title("t-SNE: Components 2 vs 3 (Random 1000-sample)")
plt.show()
### END CODE ###
```



```
In [11]: !pip install plotly
```

Requirement already satisfied: plotly in /opt/anaconda3/lib/python3.12/site-packages (6.2.0)
Requirement already satisfied: narwhals>=1.15.1 in /opt/anaconda3/lib/python3.12/site-packages (from plotly) (1.35.0)
Requirement already satisfied: packaging in /opt/anaconda3/lib/python3.12/site-packages (from plotly) (23.2)

[notice] A new release of pip is available: 25.2 -> 25.3

[notice] To update, run: `pip install --upgrade pip`

```
In [12]: ### START CODE ###  
# 3D interactive scatter plot of t-SNE components using Plotly  
import plotly.express as px  
import pandas as pd  
  
# Build DataFrame from the sampled data  
tsne_df = pd.DataFrame({  
    'TSNE1': X_sample[:, 0],  
    'TSNE2': X_sample[:, 1],  
    'TSNE3': X_sample[:, 2],  
    'critical_temp': y_sample.values  
})  
  
# Create interactive 3D scatter plot  
fig = px.scatter_3d(  
    tsne_df,  
    x='TSNE1',  
    y='TSNE2',  
    z='TSNE3',  
    color='critical_temp',  
    color_continuous_scale='viridis',  
    title='t-SNE 3D Visualization (Random 1000-sample)',  
    height=700  
)  
  
# Adjust marker size and appearance  
fig.update_traces(marker=dict(size=4, opacity=0.8))  
  
# Set up a good initial camera angle and margins  
fig.update_layout(  
    scene=dict(  
        xaxis_title='t-SNE Component 1',  
        yaxis_title='t-SNE Component 2',
```



```

        zaxis_title='t-SNE Component 3',
        camera=dict(eye=dict(x=1.5, y=1.5, z=1.0))
    ),
    margin=dict(l=0, r=0, b=0, t=40)
)

# Show the interactive figure
fig.show()
### END CODE ###

```

Note: in the code, there is a 3D t-SNE here but it doesn't render when saved as a pdf

Part 3. (5 points) Now we will plot the PCA and t-SNE projections of the data and compare the plots side-by-side to see the difference in scatters created by the two methods. You can use first 1000 data points for this.

Answer:

```

In [13]: import plotly.graph_objects as go
from plotly.subplots import make_subplots
from sklearn.decomposition import PCA
import pandas as pd

# --- 3D PCA ---
pca_3d = PCA(n_components=3, random_state=42)
X_pca_3d = pca_3d.fit_transform(X[sample_idx])

# --- Reuse existing 3D t-SNE results ---
X_tsne_3d = X_tsne[sample_idx]

# --- Build DataFrames for plotting ---
pca_df = pd.DataFrame({
    'X': X_pca_3d[:, 0],
    'Y': X_pca_3d[:, 1],
    'Z': X_pca_3d[:, 2],
    'critical_temp': y_sample.values
})
tsne_df = pd.DataFrame({
    'X': X_tsne_3d[:, 0],

```

```

    'Y': X_tsne_3d[:, 1],
    'Z': X_tsne_3d[:, 2],
    'critical_temp': y_sample.values
})

# --- Create side-by-side 3D subplots ---
fig = make_subplots(rows=1, cols=2,
                    specs=[[{'type': 'scatter3d'}, {'type': 'scatter3d'}]],
                    subplot_titles=('3D PCA', '3D t-SNE'))

# Left: PCA
fig.add_trace(
    go.Scatter3d(
        x=pca_df['X'], y=pca_df['Y'], z=pca_df['Z'],
        mode='markers',
        marker=dict(
            size=3,
            color=pca_df['critical_temp'],
            colorscale='viridis',
            opacity=0.8,
            colorbar=dict(title='critical_temp')
        ),
        name='PCA'
    ),
    row=1, col=1
)

# Right: t-SNE (reuse existing embedding)
fig.add_trace(
    go.Scatter3d(
        x=tsne_df['X'], y=tsne_df['Y'], z=tsne_df['Z'],
        mode='markers',
        marker=dict(
            size=3,
            color=tsne_df['critical_temp'],
            colorscale='viridis',
            opacity=0.8,
            showscale=False
        ),
        name='t-SNE'
    ),
    row=1, col=2
)

```

```

)

# Layout tweaks
fig.update_layout(
    height=700,
    margin=dict(l=0, r=0, b=0, t=50),
    title_text='3D PCA vs 3D t-SNE (Random 1000-sample)',
    scene=dict(
        xaxis_title='Component 1',
        yaxis_title='Component 2',
        zaxis_title='Component 3',
        camera=dict(eye=dict(x=1.5, y=1.5, z=1))
    ),
    scene2=dict(
        xaxis_title='Component 1',
        yaxis_title='Component 2',
        zaxis_title='Component 3',
        camera=dict(eye=dict(x=1.5, y=1.5, z=1))
    )
)

fig.show()

```

Note: in the code there is a 3D PCA comparison to a 3D t-SNE here, but it doesn't render when saved as a pdf. 2D comparison is below

```

In [14]: from sklearn.decomposition import PCA
from sklearn.manifold import TSNE
import matplotlib.pyplot as plt

### START CODE ###
## Obtain components from PCA
pca = PCA(n_components=2, random_state=42)
X_pca = pca.fit_transform(X[sample_idx])
### END CODE ###

### START CODE ###
## Obtain components from t-SNE
tsne_2d = TSNE(n_components=2, perplexity=300, n_iter=300, random_state=42)

```

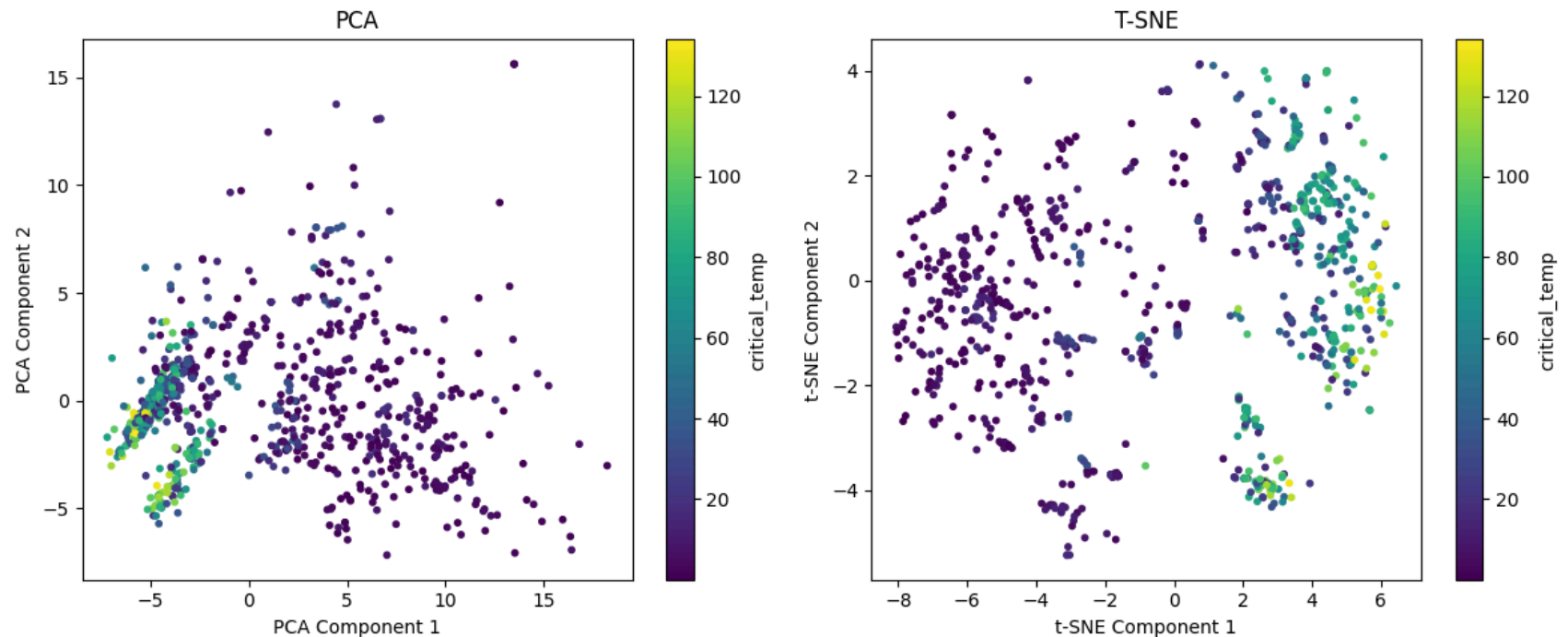
```
X_tsne_2d = tsne_2d.fit_transform(X[sample_idx])
### END CODE ###

# Plot side-by-side
plt.figure(figsize=(12, 5))

plt.subplot(1, 2, 1)
plt.title('PCA')
### START CODE ###
## Left plot: scatter plot of PCA results for the first 1000 data points
plt.scatter(X_pca[:, 0], X_pca[:, 1], c=y_sample, cmap='viridis', s=10)
plt.colorbar(label='critical_temp')
plt.xlabel('PCA Component 1')
plt.ylabel('PCA Component 2')
### END CODE ###

plt.subplot(1, 2, 2)
plt.title('T-SNE')
### START CODE ###
## Right plot: scatter plot of t-SNE results for the first 1000 data points
plt.scatter(X_tsne_2d[:, 0], X_tsne_2d[:, 1], c=y_sample, cmap='viridis', s=10)
plt.colorbar(label='critical_temp')
plt.xlabel('t-SNE Component 1')
plt.ylabel('t-SNE Component 2')
### END CODE ###

plt.tight_layout()
plt.show()
```



Q2. Classification With a Loss Matrix (10 pts)

Consider a binary classification problem with the following loss matrix: $\begin{array}{cc} & \text{Predicted class} \\ \text{True class} & C1 & C2 & \text{Reject} \\ C1 & 0 & r & c \\ C2 & s & 0 & c \end{array}$

where the cost of rejection is a constant, and the costs r and s are positive real numbers. Let $f(x) = P(C1|x)$.

Part 1. (2 points) Show that the expected loss when x is predicted as C_1 is a decreasing function of $f(x)$ while expected loss when x is predicted as C_2 is an increasing function of $f(x)$.

Hint: Express the expected losses with $f(x)$.

Answer:

```
In [15]: from IPython.display import Image, display

url = "https://raw.githubusercontent.com/AHMerrill/ml-4/main/HW4_2_1.png"
```

```
# Resize by width or height (pixels)
display(Image(url=url, width=500))
```

LET

$$f(x) = P(C_1 | x), \quad 1 - f(x) = P(C_2 | x)$$

IF WE PREDICT C_1 :

$$\begin{aligned} L(C_1 | x) &= \phi \cdot f(x) + s \cdot [1 - f(x)] \\ &= s[1 - f(x)] \\ &= s - s[f(x)] \end{aligned}$$

IF WE PREDICT C_2 :

$$\begin{aligned} L(C_2 | x) &= r \cdot f(x) + \phi \cdot [1 - f(x)] \\ &= r[f(x)] \end{aligned}$$

IF WE REJECT

$$L(\text{REJECT} | x) = c$$

TAKE DERIVATIVES w/ RESPECT TO $f(x)$

$$\frac{\partial L(C_1 | x)}{\partial f(x)} = -s < \phi \Rightarrow L(C_1 | x) \text{ decreases as } f(x) \text{ increases}$$

$$\frac{\partial L(C_2 | x)}{\partial f(x)} = r > \phi \Rightarrow L(C_2 | x) \text{ increases as } f(x) \text{ increases}$$

Part 2. (2 points) If $c=0$, show that the decision that minimizes the expected loss is to reject all instances of x .

Answer:

```
In [16]: from IPython.display import Image, display

url = "https://raw.githubusercontent.com/AHMerrill/ml-4/main/HW4_2_2.png"

# Resize by width or height (pixels)
display(Image(url=url, width=500))
```

EXPECTED LOSS FOR REJECT = \emptyset

$$f(x) = P(C_1 | x) \quad 1 - f(x) = P(C_2 | x)$$

EXPECTED LOSS OF PREDICT C_1 :

$$s[1 - f(x)] > 0$$

EXPECTED LOSS OF PREDICT C_2 :

$$r[f(x)] > 0$$

SO IF CLASS DECISION EXPECTED LOSS IS
ALWAYS GREATER THAN \emptyset : COST OF
REJECT = \emptyset YOU WILL ALWAYS REJECT

Part 3. (3 points) Let $r=4$ and $s=3$, what is the minimum value of c such that no instance of x should be rejected under the optimal decision?

Answer:

```
In [17]: from IPython.display import Image, display

url = "https://raw.githubusercontent.com/AHMerrill/ml-4/main/HW4_2_3.png"

# Resize by width or height (pixels)
display(Image(url=url, width=500))
```


	Predict			
		C_1	C_2	Reject
True	C_1	\emptyset	4	C
	C_2	3	\emptyset	C

Find C such that you never reject

Expected loss to predict $C_1 = s - sf(x)$

Expected loss to predict $C_2 = rf(x)$

Expected loss to reject = C

$C > \min(s - sf(x), rf(x))$
only needs to be greater than one of them

Find intersection $s - sf(x) = rf(x)$

$$f(x) = \frac{s}{s+r}$$

plug back in to either for expected loss

$$= \frac{rs}{r+s}$$

smallest C to guarantee rejection isn't chosen:

$$\frac{3 \cdot 4}{7} = \boxed{\frac{12}{7}}$$

Part 4 (3 points) Let $r=6$, $s=3$, and $c=1$. Determine the ranges of $f(x)$ for which the optimal decision is C1, reject and C2 respectively.

Answer:

```
In [18]: from IPython.display import Image, display

url = "https://raw.githubusercontent.com/AHMerrill/ml-4/main/HW4_2_4.png"

# Resize by width or height (pixels)
display(Image(url=url, width=500))
```

$$L(C_1|x) = 3-3f$$

$$L(C_2|x) = 6f$$

$$L(\text{Reject}|x) = 1$$

intersection of C_2 : REJECT loss

$$6f = 1$$

$$f = \frac{1}{6}$$

Intersection of C_1 : REJECT loss

$$3-3f = 1$$

$$f = \frac{2}{3}$$

PICK C_2	REJECT	PICK C_1
$f(x) < \frac{1}{6}$	$\frac{1}{6} \leq f(x) \leq \frac{2}{3}$	$f(x) > \frac{2}{3}$

Q3. Visualizing the Confusion Matrices, ROC Curves, and PR Curves (20 pts)

In this question, we will train a logistic regression classifier and a multi-layer perceptron classifier on a binary classification problem. Then, we will visualize the confusion matrices, ROC Curves, and PR Curves as well as evaluating the AU-ROC and AP of these models.

```
In [19]: ## Only use this code block if you are using Google Colab.
## If you are using Jupyter Notebook, please ignore this code block. You can directly upload the file to j
# from google.colab import files
```

```
# ## It will prompt you to select a local file. Click on "Choose Files" then select and upload the file.  
# ## Wait for the file to be 100% uploaded. You should see the name of the file once Colab has uploaded it  
# uploaded = files.upload()
```

In [20]: `!pip install --upgrade pandas`

```
Requirement already satisfied: pandas in /opt/anaconda3/lib/python3.12/site-packages (2.3.3)  
Requirement already satisfied: numpy>=1.26.0 in /opt/anaconda3/lib/python3.12/site-packages (from pandas)  
(1.26.4)  
Requirement already satisfied: python-dateutil>=2.8.2 in /opt/anaconda3/lib/python3.12/site-packages (from  
pandas) (2.9.0.post0)  
Requirement already satisfied: pytz>=2020.1 in /opt/anaconda3/lib/python3.12/site-packages (from pandas) (2  
025.2)  
Requirement already satisfied: tzdata>=2022.7 in /opt/anaconda3/lib/python3.12/site-packages (from pandas)  
(2023.3)  
Requirement already satisfied: six>=1.5 in /opt/anaconda3/lib/python3.12/site-packages (from python-dateuti  
l>=2.8.2->pandas) (1.16.0)
```

[notice] A new release of pip is available: 25.2 -> 25.3

[notice] To update, run: `pip install --upgrade pip`

In [21]: `import pandas as pd
print(pd.__version__)`

2.3.3

In [22]: `import pandas as pd
import numpy as np
import matplotlib.pyplot as plt

from sklearn.model_selection import train_test_split, ParameterGrid
from sklearn.preprocessing import StandardScaler
from sklearn.metrics import confusion_matrix, roc_auc_score, average_precision_score, ConfusionMatrixDisplay
from sklearn.linear_model import LogisticRegression
from sklearn.neural_network import MLPClassifier

pd.set_option('future.no_silent_downcasting', True)`

Dataloading and Preprocessing

```
In [23]: df = pd.read_csv(churn_path, index_col = [0])
```

```
In [24]: df.head()
```

```
Out[24]:
```

	gender	SeniorCitizen	Partner	Dependents	tenure	PhoneService	MultipleLines	InternetService	OnlineSecurity	On
0	Female	0	Yes	No	1	No	No phone service	DSL	No	
1	Male	0	No	No	34	Yes	No	DSL	Yes	
2	Male	0	No	No	2	Yes	No	DSL	Yes	
3	Male	0	No	No	45	No	No phone service	DSL	Yes	
4	Female	0	No	No	2	Yes	No	Fiber optic	No	

```
In [25]: df.info()
```

```
<class 'pandas.core.frame.DataFrame'>
Index: 7032 entries, 0 to 7042
Data columns (total 20 columns):
#   Column                Non-Null Count  Dtype
---  -
0   gender                 7032 non-null  object
1   SeniorCitizen          7032 non-null  int64
2   Partner                7032 non-null  object
3   Dependents             7032 non-null  object
4   tenure                 7032 non-null  int64
5   PhoneService           7032 non-null  object
6   MultipleLines          7032 non-null  object
7   InternetService        7032 non-null  object
8   OnlineSecurity         7032 non-null  object
9   OnlineBackup           7032 non-null  object
10  DeviceProtection       7032 non-null  object
11  TechSupport            7032 non-null  object
12  StreamingTV            7032 non-null  object
13  StreamingMovies        7032 non-null  object
14  Contract               7032 non-null  object
15  PaperlessBilling       7032 non-null  object
16  PaymentMethod          7032 non-null  object
17  MonthlyCharges         7032 non-null  float64
18  TotalCharges           7032 non-null  float64
19  Churn                  7032 non-null  object
dtypes: float64(2), int64(2), object(16)
memory usage: 1.1+ MB
```

```
In [26]: # Print out unique values of categorical columns
def print_unique_col_values(df):
    for column in df:
        if df[column].dtypes=='object':
            print(f'{column}: {df[column].unique()}')

print_unique_col_values(df)
```

```

gender: ['Female' 'Male']
Partner: ['Yes' 'No']
Dependents: ['No' 'Yes']
PhoneService: ['No' 'Yes']
MultipleLines: ['No phone service' 'No' 'Yes']
InternetService: ['DSL' 'Fiber optic' 'No']
OnlineSecurity: ['No' 'Yes' 'No internet service']
OnlineBackup: ['Yes' 'No' 'No internet service']
DeviceProtection: ['No' 'Yes' 'No internet service']
TechSupport: ['No' 'Yes' 'No internet service']
StreamingTV: ['No' 'Yes' 'No internet service']
StreamingMovies: ['No' 'Yes' 'No internet service']
Contract: ['Month-to-month' 'One year' 'Two year']
PaperlessBilling: ['Yes' 'No']
PaymentMethod: ['Electronic check' 'Mailed check' 'Bank transfer (automatic)'
'Credit card (automatic)']
Churn: ['No' 'Yes']

```

```

In [27]: # Replace values of 'no internet service' and 'no phone service' with the value 'No'
df.replace('No internet service', 'No', inplace=True)
df.replace('No phone service', 'No', inplace=True)

```

```

In [28]: # Change categorical columns with 2 categories to 0/1
yes_no_columns = ['Partner', 'Dependents', 'PhoneService', 'MultipleLines', 'OnlineSecurity', 'OnlineBackup',
                  'DeviceProtection', 'TechSupport', 'StreamingTV', 'StreamingMovies', 'PaperlessBilling', 'Chu

for col in yes_no_columns:
    df[col] = df[col].replace({'Yes': 1, 'No': 0})

df['gender'] = df['gender'].replace({'Female': 1, 'Male': 0})

for col in yes_no_columns + ['gender']:
    print(f'{col}: {df[col].unique()}')

```

```

Partner: [1 0]
Dependents: [0 1]
PhoneService: [0 1]
MultipleLines: [0 1]
OnlineSecurity: [0 1]
OnlineBackup: [1 0]
DeviceProtection: [0 1]
TechSupport: [0 1]
StreamingTV: [0 1]
StreamingMovies: [0 1]
PaperlessBilling: [1 0]
Churn: [0 1]
gender: [1 0]

```

```

In [29]: # One hot encoding for categorical columns with more than two categories
df = pd.get_dummies(data = df, columns = ['InternetService', 'Contract', 'PaymentMethod'])
print(df.columns)

```

```

Index(['gender', 'SeniorCitizen', 'Partner', 'Dependents', 'tenure',
      'PhoneService', 'MultipleLines', 'OnlineSecurity', 'OnlineBackup',
      'DeviceProtection', 'TechSupport', 'StreamingTV', 'StreamingMovies',
      'PaperlessBilling', 'MonthlyCharges', 'TotalCharges', 'Churn',
      'InternetService_DSL', 'InternetService_Fiber optic',
      'InternetService_No', 'Contract_Month-to-month', 'Contract_One year',
      'Contract_Two year', 'PaymentMethod_Bank transfer (automatic)',
      'PaymentMethod_Credit card (automatic)',
      'PaymentMethod_Electronic check', 'PaymentMethod_Mailed check'],
      dtype='object')

```

```

In [30]: # Train test split
X = df.drop('Churn', axis='columns')
y = df.Churn.astype(np.float32)

X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, random_state=42, stratify=y)
X_train, X_val, y_train, y_val = train_test_split(X_train, y_train, test_size=0.2, random_state=42, strati

```

```

In [31]: # Standardize numerical columns
cols_to_scale = ['tenure', 'MonthlyCharges', 'TotalCharges']

scaler = StandardScaler()
X_train[cols_to_scale] = scaler.fit_transform(X_train[cols_to_scale])

```



```
X_val[cols_to_scale] = scaler.transform(X_val[cols_to_scale])  
X_test[cols_to_scale] = scaler.transform(X_test[cols_to_scale])
```

```
In [32]: # With samples corresponding to the positive class being very low, we can clearly see the imbalance in our  
print('Churn occurrences in the training set \n')  
print(y_train.value_counts())  
print('\n')  
print('Churn occurrences throughout the data \n')  
print(y.value_counts())
```

Churn occurrences in the training set

```
Churn  
0.0    3304  
1.0    1196  
Name: count, dtype: int64
```

Churn occurrences throughout the data

```
Churn  
0.0    5163  
1.0    1869  
Name: count, dtype: int64
```

Part 1. (5 points) In this part, train a **logistic regression model** for the churn prediction problem. Then, evaluate its AU-ROC and AP on **train, validation, and test sets**. Finally, visualize its confusion matrices on the **validation and test set** side by side. Use `random_state=42` for training your logistic regression model.

Helpful resources:

1. [sklearn.linear_model.LogisticRegression](#)
2. [sklearn.metrics.confusion_matrix](#)
3. [sklearn.metrics.ConfusionMatrixDisplay](#)

Answer:

Default Threshold:

```

In [33]: # --- Logistic Regression with Default 0.5 Cutoff ---
        ### START CODE ###
        lr = LogisticRegression(random_state=42, max_iter=500)
        lr.fit(X_train, y_train)

        # Predicted probabilities
        train_y_pred_score_lr = lr.predict_proba(X_train)[:, 1]
        val_y_pred_score_lr   = lr.predict_proba(X_val)[:, 1]
        test_y_pred_score_lr  = lr.predict_proba(X_test)[:, 1]

        # AU-ROC and AP
        train_auroc_lr = roc_auc_score(y_train, train_y_pred_score_lr)
        val_auroc_lr   = roc_auc_score(y_val,   val_y_pred_score_lr)
        test_auroc_lr  = roc_auc_score(y_test,  test_y_pred_score_lr)

        train_ap_lr = average_precision_score(y_train, train_y_pred_score_lr)
        val_ap_lr   = average_precision_score(y_val,   val_y_pred_score_lr)
        test_ap_lr  = average_precision_score(y_test,  test_y_pred_score_lr)
        ### END CODE ###

        print(f"Logistic Regression Train AU-ROC: {train_auroc_lr:.3f} Validation AU-ROC: {val_auroc_lr:.3f} Test AU-ROC: {test_auroc_lr:.3f}")
        print(f"Logistic Regression Train AP: {train_ap_lr:.3f} Validation AP: {val_ap_lr:.3f} Test AP: {test_ap_lr:.3f}")

        # --- Pointwise metrics ---
        from sklearn.metrics import precision_score, recall_score, f1_score, accuracy_score, roc_curve

        def print_metrics(y_true, y_pred, label):
            p, r = precision_score(y_true, y_pred), recall_score(y_true, y_pred)
            f1, acc = f1_score(y_true, y_pred), accuracy_score(y_true, y_pred)
            print(f"{label:10s} Precision: {p:.3f} Recall: {r:.3f} F1: {f1:.3f} Accuracy: {acc:.3f}")

        train_preds = (train_y_pred_score_lr >= 0.5).astype(int)
        val_preds   = (val_y_pred_score_lr   >= 0.5).astype(int)
        test_preds  = (test_y_pred_score_lr  >= 0.5).astype(int)

        print("\n---- Default 0.5 Cutoff ----")
        print_metrics(y_train, train_preds, "Train")
        print_metrics(y_val,   val_preds,   "Val")
        print_metrics(y_test,  test_preds,  "Test")

        # --- ROC Curve (Training) ---

```

```

fpr, tpr, _ = roc_curve(y_train, train_y_pred_score_lr)
plt.figure(figsize=(6,5))
plt.plot(fpr, tpr, lw=2, color="royalblue", label=f"Train ROC (AUROC = {train_auroc_lr:.3f})")
plt.plot([0,1],[0,1], 'k--', lw=1)
plt.xlabel("False Positive Rate")
plt.ylabel("True Positive Rate")
plt.title("Training ROC Curve (Default Cutoff = 0.5)")
plt.legend()
plt.show()

# --- Confusion Matrices ---
fig, axes = plt.subplots(1, 2, figsize=(10, 4))
ConfusionMatrixDisplay(confusion_matrix(y_val, val_preds)).plot(ax=axes[0], colorbar=False)
axes[0].set_title("Validation Set Confusion Matrix")
ConfusionMatrixDisplay(confusion_matrix(y_test, test_preds)).plot(ax=axes[1], colorbar=False)
axes[1].set_title("Test Set Confusion Matrix")
fig.text(0.5, 1.02, "Predicted Label", ha='center', fontsize=13, fontweight='bold')
fig.text(0.02, 0.5, "True Label", ha='center', va='center', rotation='vertical', fontsize=13, fontweight='bold')
plt.tight_layout()
plt.show()

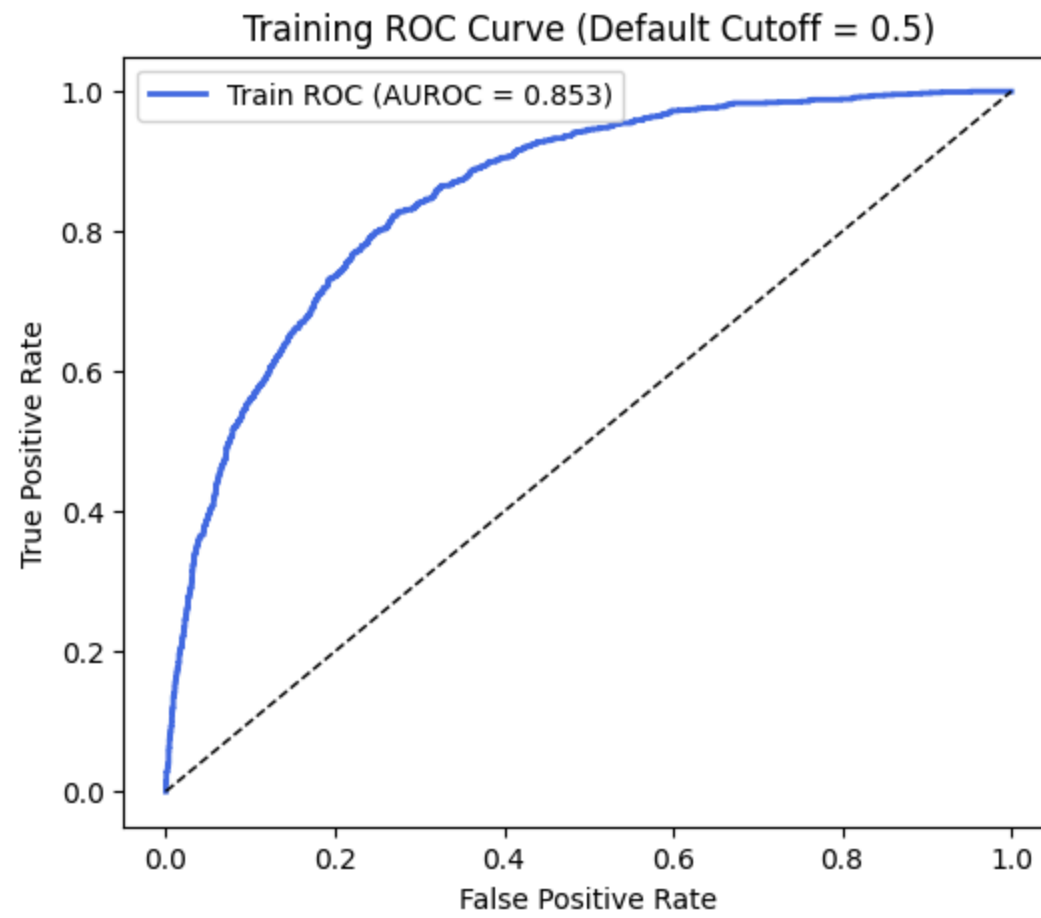
```

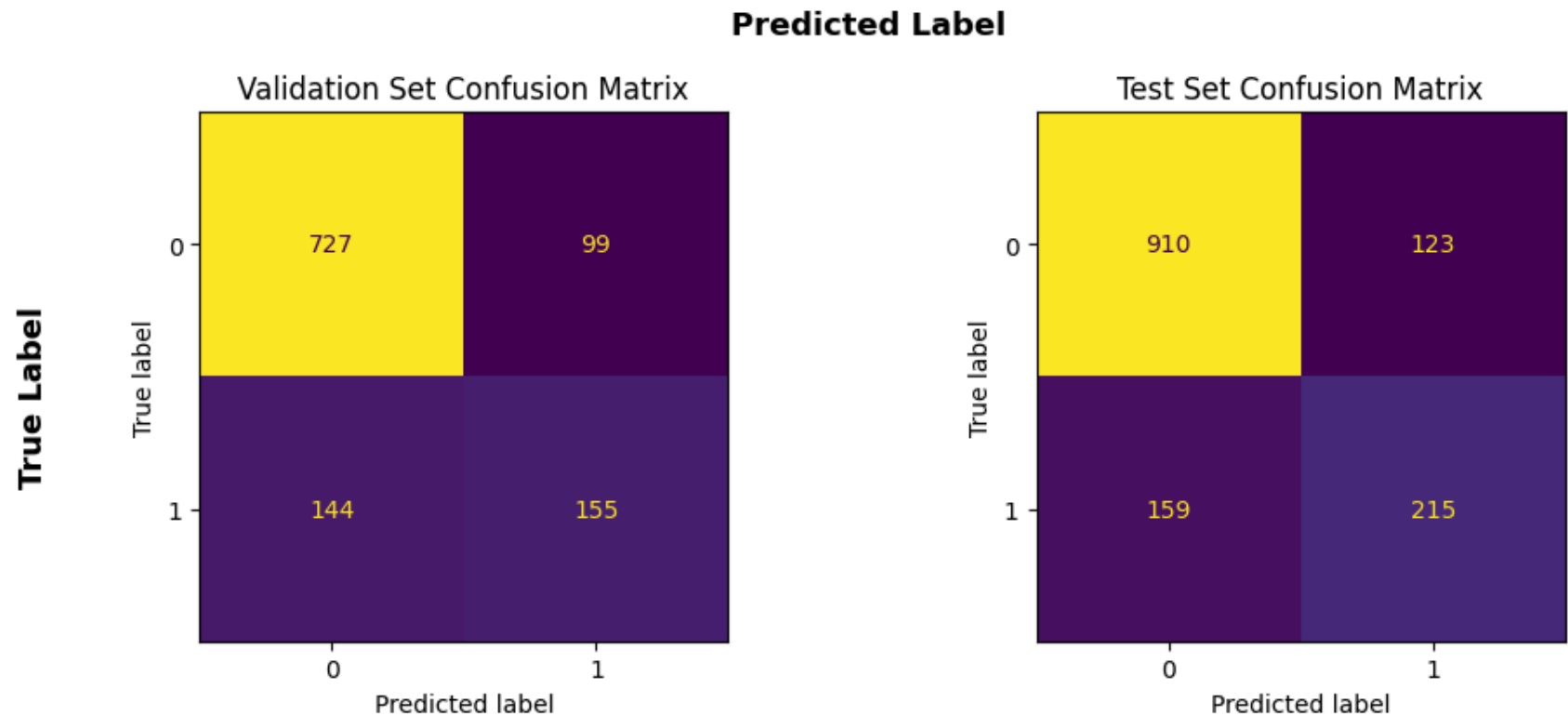
Logistic Regression Train AU-ROC: 0.853 Validation AU-ROC: 0.837 Test AU-ROC: 0.836

Logistic Regression Train AP: 0.673 Validation AP: 0.648 Test AP: 0.618

---- Default 0.5 Cutoff ----

Train	Precision: 0.669	Recall: 0.563	F1: 0.611	Accuracy: 0.810
Val	Precision: 0.610	Recall: 0.518	F1: 0.561	Accuracy: 0.784
Test	Precision: 0.636	Recall: 0.575	F1: 0.604	Accuracy: 0.800





Training ROC adjusted threshold:

```
In [34]: # --- Logistic Regression with ROC-Adjusted Cutoff ---
        ### START CODE ###
        lr = LogisticRegression(random_state=42, max_iter=500)
        lr.fit(X_train, y_train)

        # Probabilities
        train_y_pred_score_lr = lr.predict_proba(X_train)[:, 1]
        val_y_pred_score_lr   = lr.predict_proba(X_val)[:, 1]
        test_y_pred_score_lr  = lr.predict_proba(X_test)[:, 1]

        # AU-ROC & AP
        train_auroc_lr = roc_auc_score(y_train, train_y_pred_score_lr)
        val_auroc_lr   = roc_auc_score(y_val,   val_y_pred_score_lr)
```

```

test_auroc_lr = roc_auc_score(y_test, test_y_pred_score_lr)
train_ap_lr = average_precision_score(y_train, train_y_pred_score_lr)
val_ap_lr = average_precision_score(y_val, val_y_pred_score_lr)
test_ap_lr = average_precision_score(y_test, test_y_pred_score_lr)

# Optimal threshold (Youden J)
fpr, tpr, thresholds = roc_curve(y_train, train_y_pred_score_lr)
j_scores = tpr - fpr
best_threshold = thresholds[np.argmax(j_scores)]
print(f"\nOptimal threshold based on training ROC: {best_threshold:.3f}\n")
### END CODE ###

print(f"Logistic Regression Train AU-ROC: {train_auroc_lr:.3f} Validation AU-ROC: {val_auroc_lr:.3f} Test AU-ROC: {test_auroc_lr:.3f}")
print(f"Logistic Regression Train AP: {train_ap_lr:.3f} Validation AP: {val_ap_lr:.3f} Test AP: {test_ap_lr:.3f}")

# --- Pointwise metrics ---
train_preds = (train_y_pred_score_lr >= best_threshold).astype(int)
val_preds = (val_y_pred_score_lr >= best_threshold).astype(int)
test_preds = (test_y_pred_score_lr >= best_threshold).astype(int)

print("----- ROC-Adjusted Cutoff -----")
print_metrics(y_train, train_preds, "Train")
print_metrics(y_val, val_preds, "Val")
print_metrics(y_test, test_preds, "Test")

# --- ROC Curve (Training) with Marker ---
plt.figure(figsize=(6,5))
plt.plot(fpr, tpr, lw=2, color="seagreen", label=f"Train ROC (AUROC = {train_auroc_lr:.3f})")
plt.plot([0,1],[0,1], 'k--', lw=1)
plt.scatter(fpr[np.argmax(j_scores)], tpr[np.argmax(j_scores)],
            color='red', s=80, label=f"Best cutoff = {best_threshold:.3f}")
plt.xlabel("False Positive Rate")
plt.ylabel("True Positive Rate")
plt.title("Training ROC Curve (ROC-Adjusted Cutoff)")
plt.legend()
plt.show()

# --- Confusion Matrices ---
fig, axes = plt.subplots(1, 2, figsize=(10, 4))
ConfusionMatrixDisplay(confusion_matrix(y_val, val_preds)).plot(ax=axes[0], colorbar=False)
axes[0].set_title(f"Validation Confusion Matrix (Threshold = {best_threshold:.2f})")
ConfusionMatrixDisplay(confusion_matrix(y_test, test_preds)).plot(ax=axes[1], colorbar=False)

```

```
axes[1].set_title(f"Test Confusion Matrix (Threshold = {best_threshold:.2f})")
fig.text(0.5, 1.02, "Predicted Label", ha='center', fontsize=13, fontweight='bold')
fig.text(0.02, 0.5, "True Label", ha='center', va='center', rotation='vertical', fontsize=13, fontweight='bold')
plt.tight_layout()
plt.show()
```

Optimal threshold based on training ROC: 0.254

Logistic Regression Train AU-ROC: 0.853 Validation AU-ROC: 0.837 Test AU-ROC: 0.836

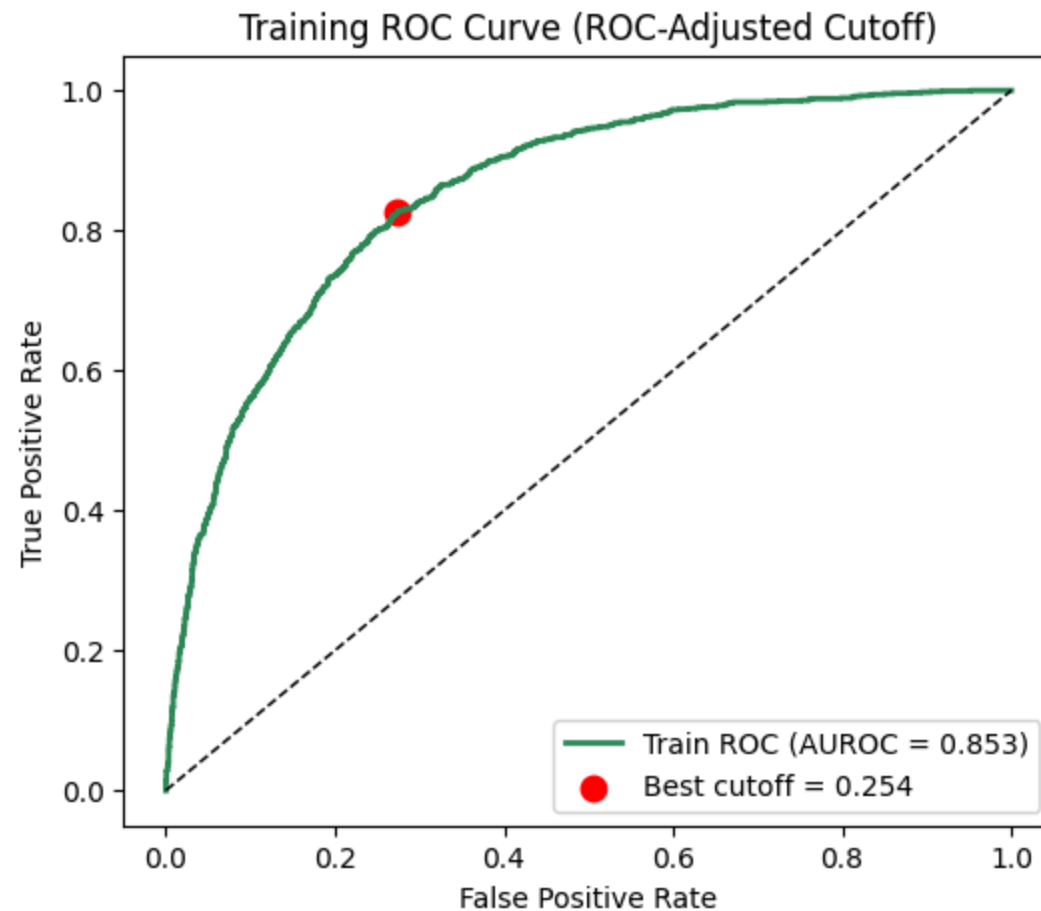
Logistic Regression Train AP: 0.673 Validation AP: 0.648 Test AP: 0.618

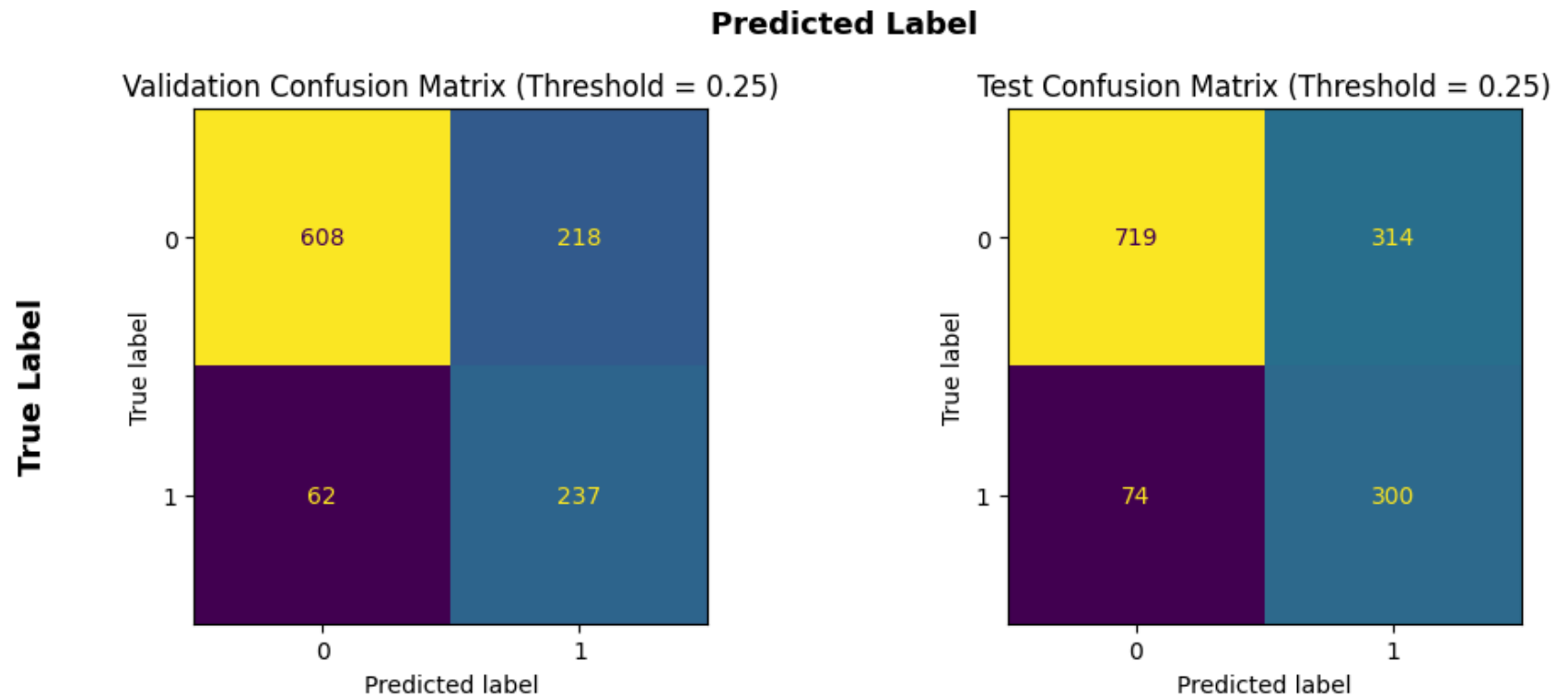
---- ROC-Adjusted Cutoff ----

Train Precision: 0.522 Recall: 0.828 F1: 0.640 Accuracy: 0.753

Val Precision: 0.521 Recall: 0.793 F1: 0.629 Accuracy: 0.751

Test Precision: 0.489 Recall: 0.802 F1: 0.607 Accuracy: 0.724





Metric	Default 0.5	ROC-Adjusted 0.25	Change	Business Interpretation
Precision (Val)	0.610	0.521	↓	More false positives — outreach costs increase
Recall (Val)	0.518	0.793	↑	Fewer churners missed — better customer retention coverage
F1 (Val)	0.561	0.629	↑	Better overall balance between precision and recall
Accuracy (Val)	0.784	0.751	↓	Lower overall correctness due to extra false positives

Tradeoff Implication

Lowering the cutoff from .5 (default) to .25 (ROC adjusted) causes the model to predict "churn" much more often.

Precision measures how many of the predicted churners actually churned, while recall measures how many actual churners were correctly identified. F1 balances these two, and accuracy reflects overall correctness. When lowering the threshold (e.g.,

from 0.5 to 0.25), recall rises because the model flags more positives, but precision and accuracy drop since more non-churners are incorrectly flagged. In business terms, this means catching more true churners (fewer missed opportunities to retain customers) at the cost of targeting more customers who would have stayed anyway. The preferred balance depends on whether the company prioritizes minimizing churn or avoiding unnecessary retention costs.

Part 2a. (3 points) In this part, we will train a **multi-layer perceptron** (MLP) for the churn prediction problem. For simplicity and consistency, use sklearn's `MLPClassifier` with `random_state=42`. Before training the final MLP, first do hyper-parameter selection by validation average precision score.

Hint: Try out different `hidden_layer_sizes` and `learning_rate_init` configurations for `MLPClassifier`.

Helpful resources:

1. [sklearn.neural_network.MLPClassifier](#)
2. [sklearn.metrics.average_precision_score](#)
3. [sklearn.model_selection.ParameterGrid](#)

Answer:

```
In [35]: # Define hyper-parameter search space, train models with different hyper-parameters,
# and record the best hyper-parameters and validation AP
### START CODE ###

# Define parameter grid
param_grid = {
    "hidden_layer_sizes": [(32,), (64,), (128,), (64, 32), (128, 64)],
    "learning_rate_init": [0.001, 0.01, 0.05]
}

best_val_ap_mlp = -np.inf
best_hparams_mlp = None

for params in ParameterGrid(param_grid):
    mlp = MLPClassifier(random_state=42,
                        max_iter=1000,
                        hidden_layer_sizes=params["hidden_layer_sizes"],
                        learning_rate_init=params["learning_rate_init"])
    mlp.fit(X_train, y_train)
```

```

# Predict probabilities for validation set
val_probs = mlp.predict_proba(X_val)[: , 1]
val_ap = average_precision_score(y_val, val_probs)

if val_ap > best_val_ap_mlp:
    best_val_ap_mlp = val_ap
    best_hparams_mlp = params

### END CODE ###

print(f"Best Hyper-parameters: {best_hparams_mlp} Best Val Average Precision: {best_val_ap_mlp:.3f}")

```

Best Hyper-parameters: {'hidden_layer_sizes': (32,), 'learning_rate_init': 0.001} Best Val Average Precision: 0.620

Part 2b. (2 points) Use your selected best hyper-parameters to train a final MLP. Then, evaluate its AU-ROC and AP on **train, validation, and test sets**. Finally, visualize its confusion matrices on the **validation and test set** side by side.

Answer:

```

In [36]: # Initialize and fit MLP
### START CODE ###
mlp_best = MLPClassifier(
    random_state=42,
    hidden_layer_sizes=(32,),
    learning_rate_init=0.001,
    max_iter=500
)
mlp_best.fit(X_train, y_train)
### END CODE ###

# Evaluate AU-ROC and AP on train/validation/test sets
### START CODE ###
# Predicted probabilities for the positive class (1)
train_y_pred_score_mlp = mlp_best.predict_proba(X_train)[: , 1]
val_y_pred_score_mlp = mlp_best.predict_proba(X_val)[: , 1]
test_y_pred_score_mlp = mlp_best.predict_proba(X_test)[: , 1]

# AU-ROC

```

```

train_auroc_mlp = roc_auc_score(y_train, train_y_pred_score_mlp)
val_auroc_mlp = roc_auc_score(y_val, val_y_pred_score_mlp)
test_auroc_mlp = roc_auc_score(y_test, test_y_pred_score_mlp)

# Average Precision (AP)
train_ap_mlp = average_precision_score(y_train, train_y_pred_score_mlp)
val_ap_mlp = average_precision_score(y_val, val_y_pred_score_mlp)
test_ap_mlp = average_precision_score(y_test, test_y_pred_score_mlp)
### END CODE ###

print(f"MLP Train AU-ROC: {train_auroc_mlp:.3f} Validation AU-ROC: {val_auroc_mlp:.3f} Test AU-ROC: {test_auroc_mlp:.3f}")
print(f"MLP Train AP: {train_ap_mlp:.3f} Validation AP: {val_ap_mlp:.3f} Test AP: {test_ap_mlp:.3f}")

# ---- Default 0.5 Cutoff ----
train_preds = (train_y_pred_score_mlp >= 0.5).astype(int)
val_preds = (val_y_pred_score_mlp >= 0.5).astype(int)
test_preds = (test_y_pred_score_mlp >= 0.5).astype(int)

def print_metrics(y_true, y_pred, split):
    p = precision_score(y_true, y_pred)
    r = recall_score(y_true, y_pred)
    f1 = f1_score(y_true, y_pred)
    acc = accuracy_score(y_true, y_pred)
    print(f"{split:<10} Precision: {p:.3f} Recall: {r:.3f} F1: {f1:.3f} Accuracy: {acc:.3f}")

print("\n---- Default 0.5 Cutoff ----")
print_metrics(y_train, train_preds, "Train")
print_metrics(y_val, val_preds, "Val")
print_metrics(y_test, test_preds, "Test")

# --- Confusion matrices ---
fig, axes = plt.subplots(1, 2, figsize=(10, 4))
ConfusionMatrixDisplay(confusion_matrix(y_val, val_preds)).plot(ax=axes[0], colorbar=False)
axes[0].set_title("Validation (Threshold = 0.5)")
ConfusionMatrixDisplay(confusion_matrix(y_test, test_preds)).plot(ax=axes[1], colorbar=False)
axes[1].set_title("Test (Threshold = 0.5)")
plt.suptitle("MLP Confusion Matrices (Default 0.5 Threshold)", fontsize=14, fontweight="bold")
plt.tight_layout()
plt.show()

```

MLP Train AU-ROC: 0.902 Validation AU-ROC: 0.822 Test AU-ROC: 0.820

MLP Train AP: 0.766 Validation AP: 0.620 Test AP: 0.598

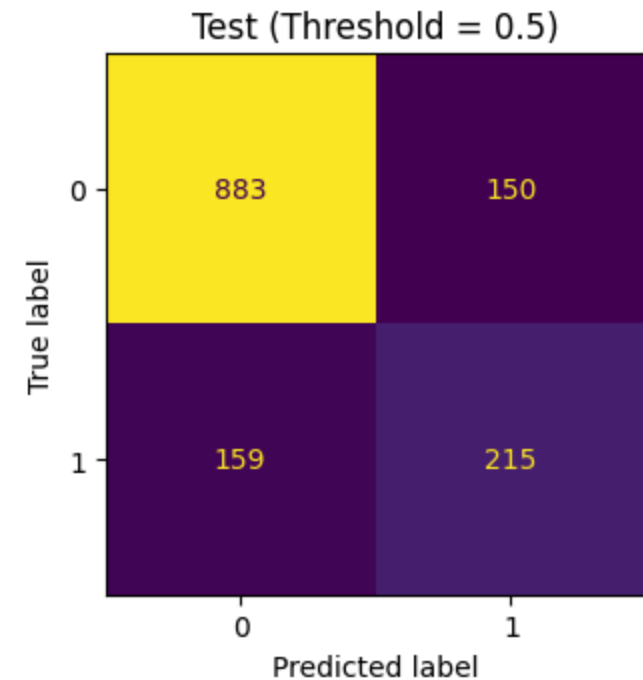
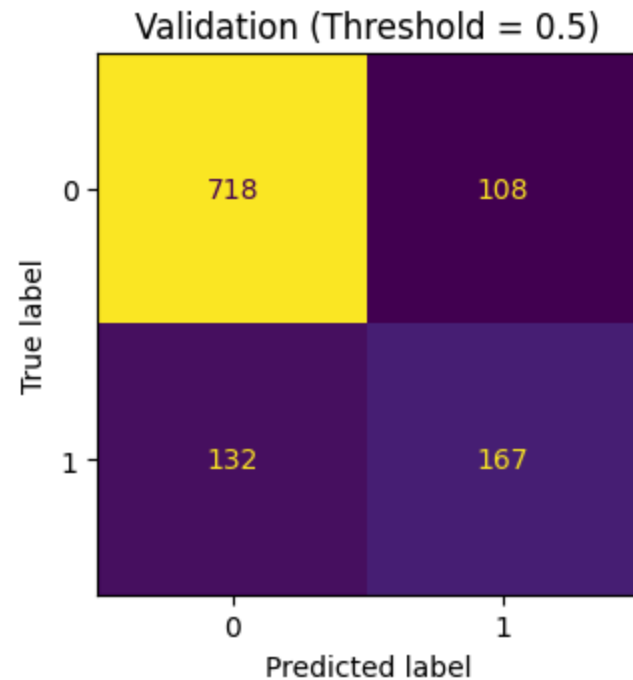
----- Default 0.5 Cutoff -----

Train Precision: 0.717 Recall: 0.665 F1: 0.690 Accuracy: 0.841

Val Precision: 0.607 Recall: 0.559 F1: 0.582 Accuracy: 0.787

Test Precision: 0.589 Recall: 0.575 F1: 0.582 Accuracy: 0.780

MLP Confusion Matrices (Default 0.5 Threshold)



```
In [37]: from sklearn.metrics import roc_curve, precision_score, recall_score, f1_score, accuracy_score
```

```
# Initialize and fit MLP
### START CODE ###
mlp_best = MLPClassifier(
    random_state=42,
    hidden_layer_sizes=(32,),
    learning_rate_init=0.001,
    max_iter=1000
)
```

```

mlp_best.fit(X_train, y_train)
### END CODE ###

# Evaluate AU-ROC and AP on train/validation/test sets
### START CODE ###
train_y_pred_score_mlp = mlp_best.predict_proba(X_train)[: , 1]
val_y_pred_score_mlp = mlp_best.predict_proba(X_val)[: , 1]
test_y_pred_score_mlp = mlp_best.predict_proba(X_test)[: , 1]

# AU-ROC
train_auroc_mlp = roc_auc_score(y_train, train_y_pred_score_mlp)
val_auroc_mlp = roc_auc_score(y_val, val_y_pred_score_mlp)
test_auroc_mlp = roc_auc_score(y_test, test_y_pred_score_mlp)

# Average Precision (AP)
train_ap_mlp = average_precision_score(y_train, train_y_pred_score_mlp)
val_ap_mlp = average_precision_score(y_val, val_y_pred_score_mlp)
test_ap_mlp = average_precision_score(y_test, test_y_pred_score_mlp)
### END CODE ###

print(f"MLP Train AU-ROC: {train_auroc_mlp:.3f} Validation AU-ROC: {val_auroc_mlp:.3f} Test AU-ROC: {test_auroc_mlp:.3f}")
print(f"MLP Train AP: {train_ap_mlp:.3f} Validation AP: {val_ap_mlp:.3f} Test AP: {test_ap_mlp:.3f}")

# --- Determine optimal threshold based on training ROC curve ---
fpr, tpr, thresholds = roc_curve(y_train, train_y_pred_score_mlp)
j_scores = tpr - fpr
best_threshold = thresholds[np.argmax(j_scores)]
print(f"\nOptimal threshold based on training ROC: {best_threshold:.3f}")

# --- Apply threshold ---
train_preds = (train_y_pred_score_mlp >= best_threshold).astype(int)
val_preds = (val_y_pred_score_mlp >= best_threshold).astype(int)
test_preds = (test_y_pred_score_mlp >= best_threshold).astype(int)

# --- Compute pointwise metrics ---
def print_metrics(y_true, y_pred, split):
    p = precision_score(y_true, y_pred)
    r = recall_score(y_true, y_pred)
    f1 = f1_score(y_true, y_pred)
    acc = accuracy_score(y_true, y_pred)
    print(f"{split}<10} Precision: {p:.3f} Recall: {r:.3f} F1: {f1:.3f} Accuracy: {acc:.3f}")

```

```

print("\n---- ROC-Adjusted Cutoff ----")
print_metrics(y_train, train_preds, "Train")
print_metrics(y_val, val_preds, "Val")
print_metrics(y_test, test_preds, "Test")

# --- Confusion matrices ---
fig, axes = plt.subplots(1, 2, figsize=(10, 4))
ConfusionMatrixDisplay(confusion_matrix(y_val, val_preds)).plot(ax=axes[0], colorbar=False)
axes[0].set_title(f"Validation (Threshold = {best_threshold:.2f})")
ConfusionMatrixDisplay(confusion_matrix(y_test, test_preds)).plot(ax=axes[1], colorbar=False)
axes[1].set_title(f"Test (Threshold = {best_threshold:.2f})")
plt.suptitle("MLP Confusion Matrices (ROC-Adjusted Threshold)", fontsize=14, fontweight="bold")
plt.tight_layout()
plt.show()

```

MLP Train AU-ROC: 0.902 Validation AU-ROC: 0.822 Test AU-ROC: 0.820

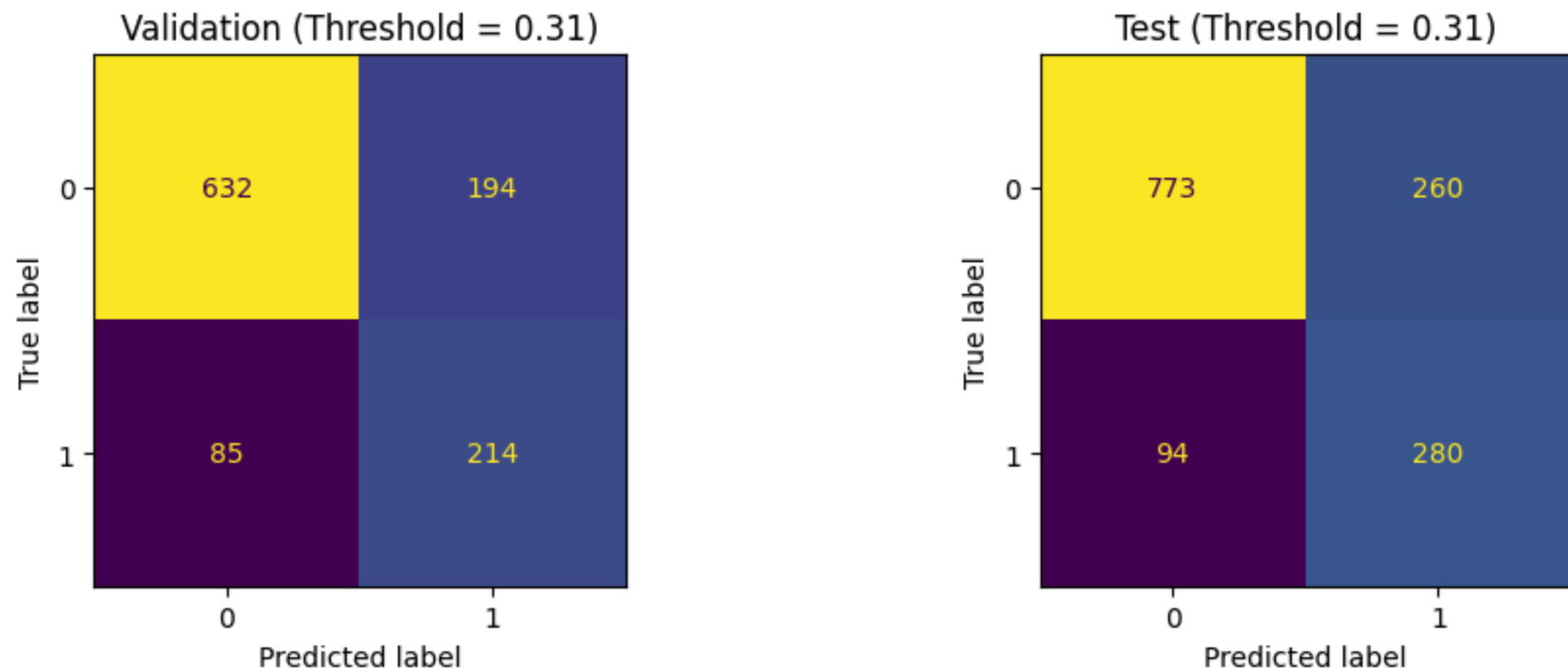
MLP Train AP: 0.766 Validation AP: 0.620 Test AP: 0.598

Optimal threshold based on training ROC: 0.312

---- ROC-Adjusted Cutoff ----

Train	Precision: 0.609	Recall: 0.844	F1: 0.708	Accuracy: 0.815
Val	Precision: 0.525	Recall: 0.716	F1: 0.605	Accuracy: 0.752
Test	Precision: 0.519	Recall: 0.749	F1: 0.613	Accuracy: 0.748

MLP Confusion Matrices (ROC-Adjusted Threshold)



once again, if you lower the threshold you will predict more positives. This would be a good thing if not missing a churner is more important than creating false positives

MLP Test Performance Comparison

Metric	Default Threshold (0.5)	ROC-Adjusted Threshold (0.312)
AU-ROC	0.820	0.820
Average Precision (AP)	0.598	0.598
Precision	0.589	0.519

Metric	Default Threshold (0.5)	ROC-Adjusted Threshold (0.312)
Recall	0.575	0.749
F1 Score	0.582	0.613
Accuracy	0.780	0.748
Threshold	0.5	0.312

Part 3. (3 points) Plot the ROC curves of the trained logistic regression and MLP models on the validation and test sets side by side. The left plot is for validation set and the right plot is for test set. Each plot consists of two ROC curves, one of the logistic regression model and one of the MLP. Please also display the AU-ROC (or AUC) to the **3rd decimal place** in the plot as well.

Helpful resources:

1. [sklearn.metrics.RocCurveDisplay](#)

Answer:

```
In [38]: # Plot ROC curves
fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(12, 5))

### START CODE ###

# --- Validation ROC ---
RocCurveDisplay.from_predictions(
    y_val,
    val_y_pred_score_lr,
    name=f"Logistic Regression (AUC = {val_auroc_lr:.3f})",
    ax=ax1
)
RocCurveDisplay.from_predictions(
    y_val,
    val_y_pred_score_mlp,
    name=f"MLP (AUC = {val_auroc_mlp:.3f})",
    ax=ax1
)
ax1.set_title("Validation Set ROC Curves")
```



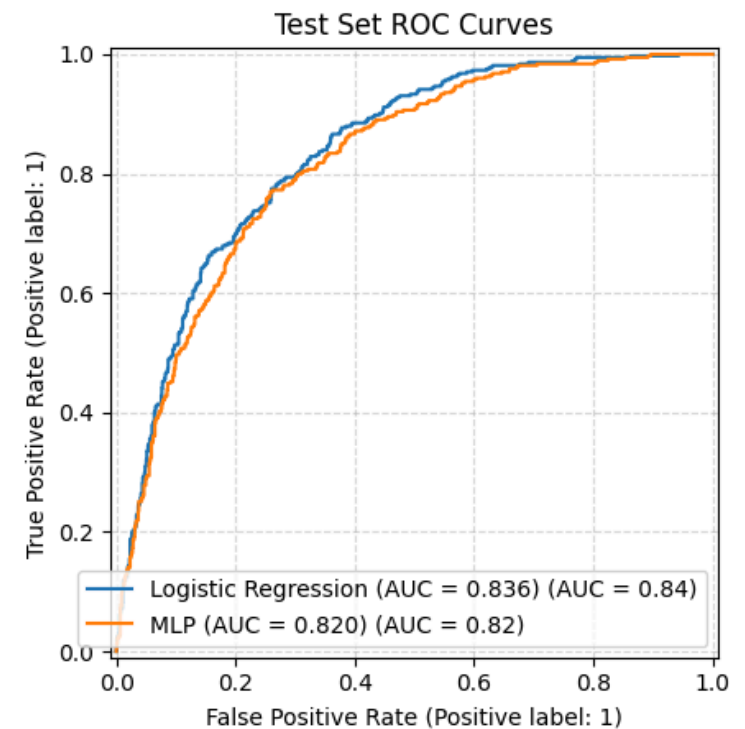
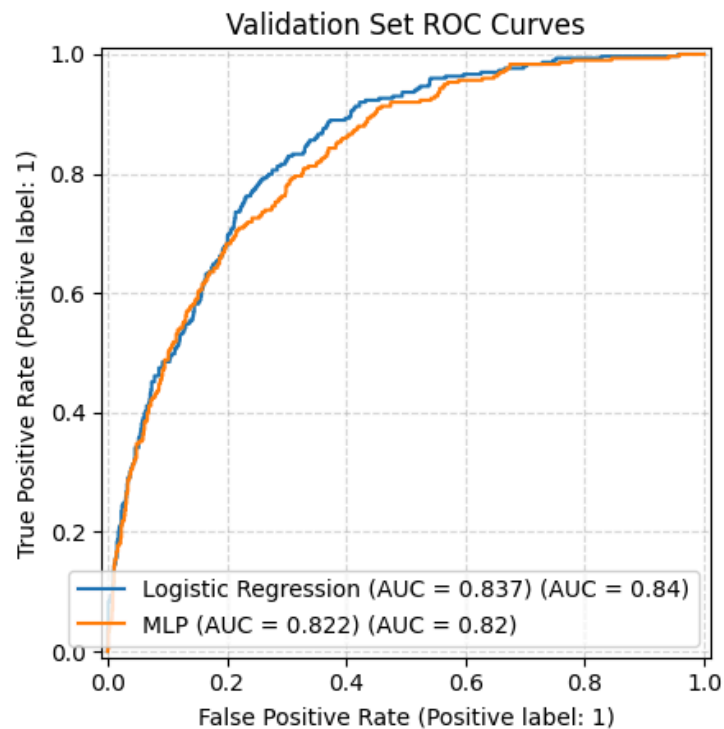
```
ax1.legend(loc="lower right")
ax1.grid(True, linestyle="--", alpha=0.5)

# --- Test ROC ---
RocCurveDisplay.from_predictions(
    y_test,
    test_y_pred_score_lr,
    name=f"Logistic Regression (AUC = {test_auroc_lr:.3f})",
    ax=ax2
)
RocCurveDisplay.from_predictions(
    y_test,
    test_y_pred_score_mlp,
    name=f"MLP (AUC = {test_auroc_mlp:.3f})",
    ax=ax2
)
ax2.set_title("Test Set ROC Curves")
ax2.legend(loc="lower right")
ax2.grid(True, linestyle="--", alpha=0.5)

### END CODE ###

plt.suptitle("ROC Curve Comparison: Logistic Regression vs MLP", fontsize=14, fontweight="bold")
plt.tight_layout()
plt.show()
```

ROC Curve Comparison: Logistic Regression vs MLP



Part 4. (3 points) Plot the PR curves of the trained logistic regression and MLP models on the validation and test sets side by side. The left plot is for validation set and the right plot is for test set. Each plot consists of two PR curves, one of the logistic regression model and one of the MLP. Please also display the average precision (AP) to the **3rd decimal place** in the plot as well.

Helpful resources:

1. [sklearn.metrics.PrecisionRecallDisplay](#)

Answer:

```
In [39]: fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(12, 5))

### START CODE ###
```

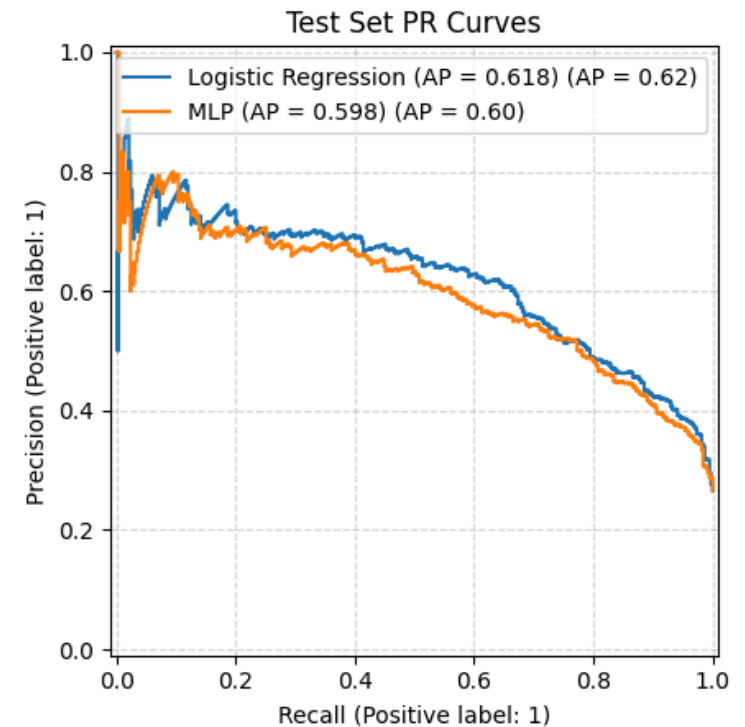
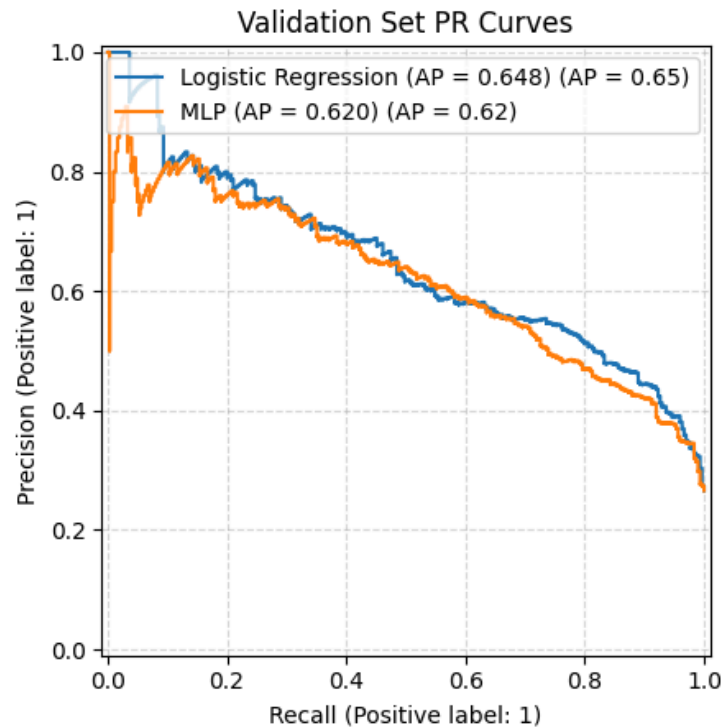
```
# --- Validation PR Curves ---
PrecisionRecallDisplay.from_predictions(
    y_val,
    val_y_pred_score_lr,
    name=f"Logistic Regression (AP = {val_ap_lr:.3f})",
    ax=ax1
)
PrecisionRecallDisplay.from_predictions(
    y_val,
    val_y_pred_score_mlp,
    name=f"MLP (AP = {val_ap_mlp:.3f})",
    ax=ax1
)
ax1.set_title("Validation Set PR Curves")
ax1.legend(loc="upper right")
ax1.grid(True, linestyle="--", alpha=0.5)

# --- Test PR Curves ---
PrecisionRecallDisplay.from_predictions(
    y_test,
    test_y_pred_score_lr,
    name=f"Logistic Regression (AP = {test_ap_lr:.3f})",
    ax=ax2
)
PrecisionRecallDisplay.from_predictions(
    y_test,
    test_y_pred_score_mlp,
    name=f"MLP (AP = {test_ap_mlp:.3f})",
    ax=ax2
)
ax2.set_title("Test Set PR Curves")
ax2.legend(loc="upper right")
ax2.grid(True, linestyle="--", alpha=0.5)

### END CODE ###

plt.suptitle("Precision-Recall Curves: Logistic Regression vs MLP", fontsize=14, fontweight="bold")
plt.tight_layout()
plt.show()
```

Precision-Recall Curves: Logistic Regression vs MLP



Part 5. (4 points) Briefly describe your takeaways from the plotted ROC and PR curves and how do the two models you trained compare.

Answer:

- ROC is showing the probability that the model ranks a random positive higher than a random negative. It shows how well the model separates the two classes overall. Logistic regression and MLP perform relatively similar, but logistic regression out-performs slightly. This suggests the data is closer to being linearly separable, and the non-linear ReLU of the MLP adds a complexity that hurts the model.
- The PR curve is typically more informative if the dataset is imbalance, and it shows how well the model maintains precision while trying to capture more positives. Here again, logistic regression slightly out-performs MLP, showing that it can capture more true positives without as many false alarms.

- Overall logistic regression is a simpler and more effective model.

Q4. Concepts about AU-ROC and AU-PRC (10 pts)

Part 1. (4 points) Consider a binary classification problem and a no-skill random classifier $f(x)$ that outputs a number randomly sampled from $U[0,1]$ to be the predicted probability of x being positive. In other words, the returned probability from $f(x)$ actually does not depend on x (hence no-skill). Why is the Area Under the Precision-Recall Curve (AU-PRC) of $f(x)$ the prior probability of the positive class, i.e. $P(y = 1)$?

HINT: Think about the definition of precision and recall, and how they relate to the decision threshold.

Answer:

A random classifier with no information about x assigns probabilities uniformly at random, so its predictions are independent of the true class labels.

by definition, precision = $TP / (TP + FP)$ and recall = $TP / (TP + FN)$

for a no-skill classifier, the points predicted as positive at any threshold are just a random subset of all samples. the expected fraction of true positives among them equals the overall fraction of positives in the dataset, $P(y=1)$

so, precision stays constant for all recall levels, making the curve a flat line and the area underneath is $P(y=1)$, which is the prior probability of the positive class.

Part 2. (3 points) Consider the previous binary classification problem and classifier. Why is the Area Under the Receiver Operating Characteristic Curve (AU-ROC) of $f(x)$ 0.5 ?

HINT: Think about the definition of true positive rate and false positive rate, and how they relate to the decision threshold.

Answer:

the roc curve depends only on the relative ranking of predicted scores. a no-skill classifier has no relationship between its predicted scores and the true class labels, so it ranks positive and negative examples randomly—each is equally likely to receive a higher score.

as the decision threshold moves, the true-positive rate and false-positive rate both increase at about the same rate, producing points that fall along the diagonal line from (0,0) to (1,1). the area under that diagonal is 0.5, showing the classifier has a 50 percent chance of ranking a randomly chosen positive higher than a randomly chosen negative.

it does not depend on class balance; even if the data is imbalanced, the roc curve stays diagonal because tpr and fpr scale together.

Part 3. (3 points) Why is AP a better metric than AU-ROC under an imbalanced binary classification problem where the positive instances are extremely rare compared to negative instances?

Answer:

even though AU-ROC itself doesn't depend on class balance, it can overestimate performance in imbalanced datasets because the large number of negatives keeps the false-positive rate small. AU-PRC (average precision) focuses only on the positive class, so it better reflects how well the model identifies rare positives without producing too many false alarms.