

update_convex_project_V2

May 7, 2025

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3 Install library

```
[3]: pip install ucimlrepo
```

```
Requirement already satisfied: ucimlrepo in c:\users\dell\anaconda3\lib\site-  
packages (0.0.7)  
Requirement already satisfied: certifi>=2020.12.5 in  
c:\users\dell\anaconda3\lib\site-packages (from ucimlrepo) (2022.9.14)  
Requirement already satisfied: pandas>=1.0.0 in  
c:\users\dell\anaconda3\lib\site-packages (from ucimlrepo) (2.2.3)  
Requirement already satisfied: pytz>=2020.1 in c:\users\dell\anaconda3\lib\site-  
packages (from pandas>=1.0.0->ucimlrepo) (2024.2)  
Requirement already satisfied: tzdata>=2022.7 in  
c:\users\dell\anaconda3\lib\site-packages (from pandas>=1.0.0->ucimlrepo)  
(2024.2)  
Requirement already satisfied: numpy>=1.22.4 in  
c:\users\dell\anaconda3\lib\site-packages (from pandas>=1.0.0->ucimlrepo)  
(2.0.2)  
Requirement already satisfied: python-dateutil>=2.8.2 in  
c:\users\dell\anaconda3\lib\site-packages (from pandas>=1.0.0->ucimlrepo)  
(2.8.2)  
Requirement already satisfied: six>=1.5 in c:\users\dell\anaconda3\lib\site-  
packages (from python-dateutil>=2.8.2->pandas>=1.0.0->ucimlrepo) (1.16.0)  
Note: you may need to restart the kernel to use updated packages.
```

4 Load Libraries

```
[4]: import numpy as np  
import pandas as pd  
import matplotlib.pyplot as plt  
import seaborn as sns  
  
from ucimlrepo import fetch_ucirepo
```

```

from sklearn.decomposition import PCA
# for detecting errors
from scipy.stats import zscore

from sklearn.preprocessing import StandardScaler

from sklearn.model_selection import train_test_split
from sklearn.preprocessing import RobustScaler # For handling outliers

# Baseline Model Implementation: Logistic Regression and Dummy Classifier
from sklearn.linear_model import LogisticRegression
from sklearn.metrics import accuracy_score, confusion_matrix, \
    classification_report
from sklearn.dummy import DummyClassifier
import seaborn as sns
import matplotlib.pyplot as plt

```

5 fetch dataset

```
[5]: banknote_authentication = fetch_ucirepo(id=267)
```

6 convert to data frame

```

[6]: # Convert features and targets to DataFrame
df_features = pd.DataFrame(banknote_authentication.data.features, \
    columns=banknote_authentication.feature_names)
# df_targets = pd.Series(banknote_authentication.data.targets["class"], \
    name='class')

# Combine into one DataFrame
df = pd.concat([df_features, banknote_authentication.data.targets["class"]], \
    axis=1)

print(df.head())

```

	variance	skewness	curtosis	entropy	class
0	3.62160	8.6661	-2.8073	-0.44699	0
1	4.54590	8.1674	-2.4586	-1.46210	0
2	3.86600	-2.6383	1.9242	0.10645	0
3	3.45660	9.5228	-4.0112	-3.59440	0
4	0.32924	-4.4552	4.5718	-0.98880	0

```
[7]: df.head(10)
```

```
[7]:
```

	variance	skewness	curtosis	entropy	class
0	3.62160	8.6661	-2.80730	-0.44699	0
1	4.54590	8.1674	-2.45860	-1.46210	0
2	3.86600	-2.6383	1.92420	0.10645	0
3	3.45660	9.5228	-4.01120	-3.59440	0
4	0.32924	-4.4552	4.57180	-0.98880	0
5	4.36840	9.6718	-3.96060	-3.16250	0
6	3.59120	3.0129	0.72888	0.56421	0
7	2.09220	-6.8100	8.46360	-0.60216	0
8	3.20320	5.7588	-0.75345	-0.61251	0
9	1.53560	9.1772	-2.27180	-0.73535	0

7 Initial EDA

7.1 Dataset Overview

- **Instances:** 1372
- **Features:** 4 continuous features
- **Target:** class (0 = forged, 1 = genuine)
- **Missing Values:** None

7.1.1 Banknote Authentication Dataset - Feature Descriptions

- **variance:** Spread of pixel intensities (texture contrast).
- **skewness:** Asymmetry of pixel intensity distribution.
- **curtosis:** Sharpness or tail heaviness of the distribution.
- **entropy:** Randomness or complexity in the image.
- **class:** Target label — 0 for forged, 1 for genuine banknote.

```
[8]: df.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 1372 entries, 0 to 1371
Data columns (total 5 columns):
#   Column      Non-Null Count  Dtype
---  -
0   variance    1372 non-null   float64
1   skewness    1372 non-null   float64
2   curtosis    1372 non-null   float64
3   entropy     1372 non-null   float64
4   class       1372 non-null   int64
```

```
dtypes: float64(4), int64(1)
memory usage: 53.7 KB
```

7.1.2 We Observe:

- **Feature Variability:**
 - Features such as **variance**, **skewness**, **curtosis**, and **entropy** show a wide range of values, indicating significant diversity in the data distribution.
 - The **mean values** of the features are close to 0, but the **standard deviations** are high, reflecting large variability.
- **Feature Skewness and Kurtosis:**
 - The **skewness** and **kurtosis** of some features suggest they might have extreme values or be highly skewed.
- **Class Imbalance:**
 - The dataset has an imbalanced class distribution, with more instances of **class 0 (forged)** compared to **class 1 (genuine)**.

```
[9]: df.describe()
```

```
[9]:
```

	variance	skewness	curtosis	entropy	class
count	1372.000000	1372.000000	1372.000000	1372.000000	1372.000000
mean	0.433735	1.922353	1.397627	-1.191657	0.444606
std	2.842763	5.869047	4.310030	2.101013	0.497103
min	-7.042100	-13.773100	-5.286100	-8.548200	0.000000
25%	-1.773000	-1.708200	-1.574975	-2.413450	0.000000
50%	0.496180	2.319650	0.616630	-0.586650	0.000000
75%	2.821475	6.814625	3.179250	0.394810	1.000000
max	6.824800	12.951600	17.927400	2.449500	1.000000

8 Data Preprocessing

8.1 1-Data Cleaning

- **Handling missing values:** We can check for null values using `.isnull()` and fill them in using `.fillna()`
- **Removing duplicates:** We can use `.drop_duplicates()`

```
[10]: df.isnull().sum().sum()
```

```
[10]: np.int64(0)
```

```
[11]: df.duplicated().sum()
```

```
[11]: np.int64(24)
```

```
[12]: df.drop_duplicates(inplace = True)
```

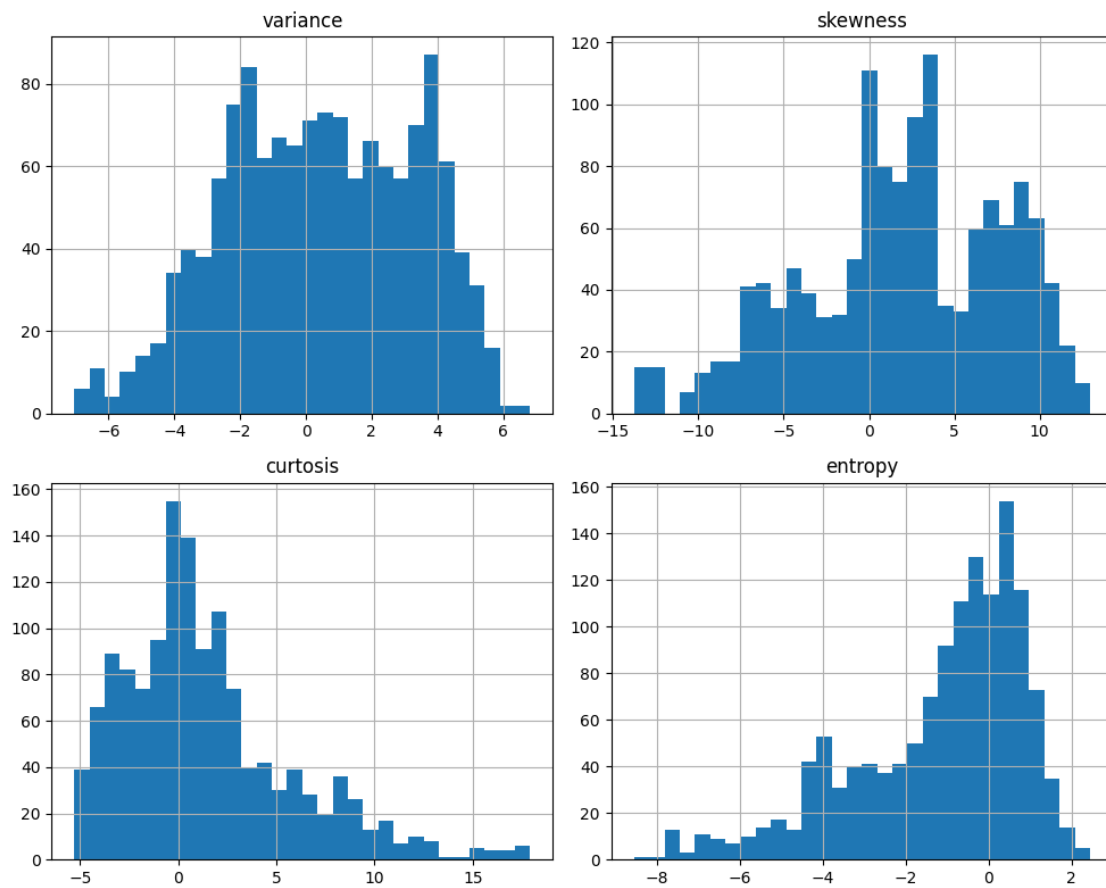
```
[13]: df.duplicated().sum()
```

```
[13]: np.int64(0)
```

9 Univariate Analysis

9.1 Plotting Histograms

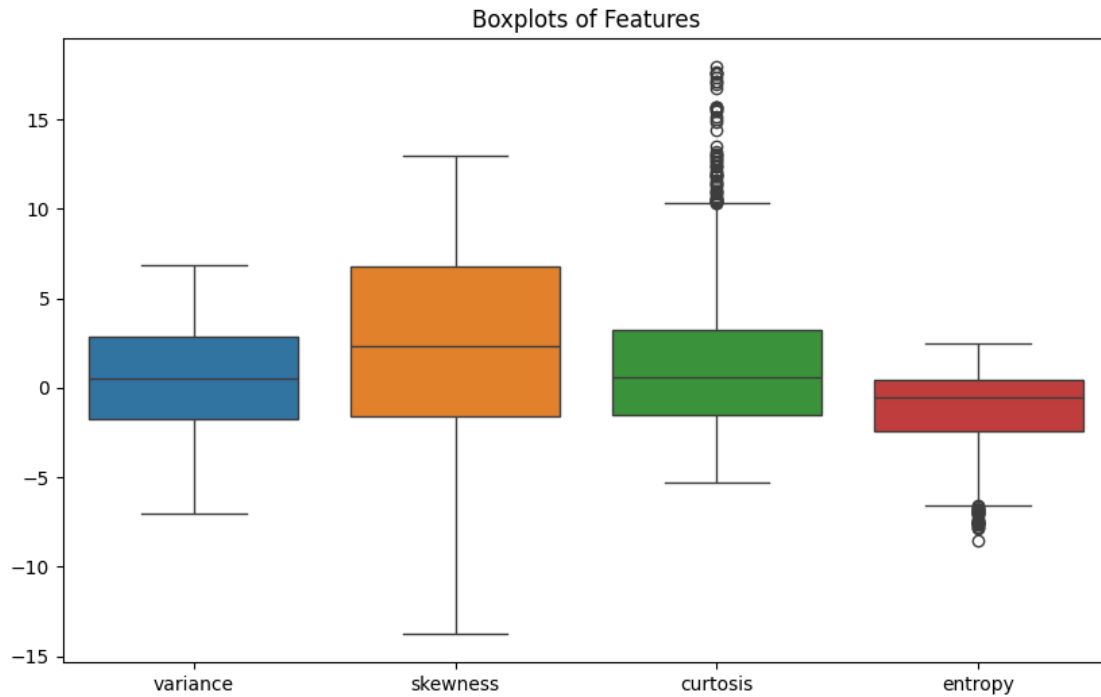
```
[14]: df[['variance', 'skewness', 'curtosis', 'entropy']].hist(bins=30, figsize=(10, 8))  
plt.tight_layout()  
plt.show()
```



9.2 Boxplots

9.2.1 decision we won't remove outliers since they are of metrics of the images and has meaningful info

```
[15]: plt.figure(figsize=(10, 6))
sns.boxplot(data=df[['variance', 'skewness', 'curtosis', 'entropy']])
plt.title('Boxplots of Features')
plt.show()
```

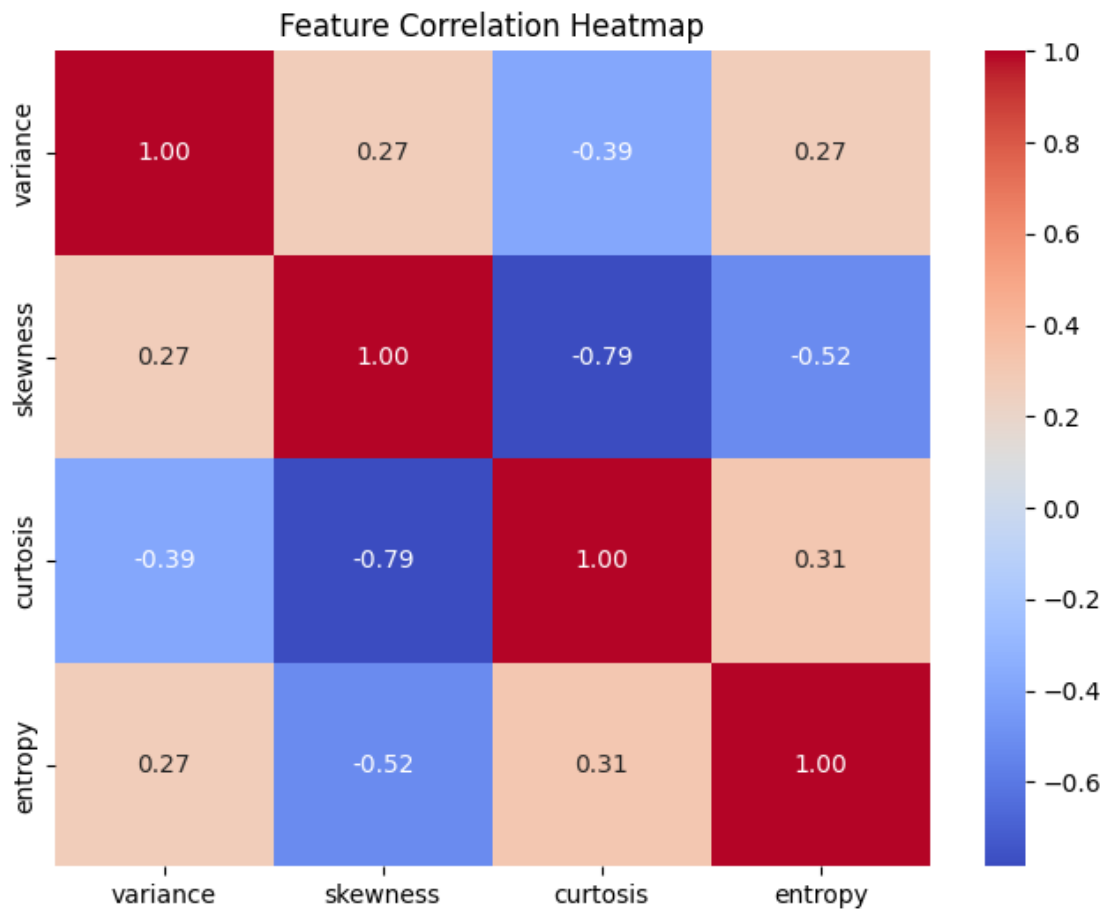


9.3 Boxplots

10 Bivariate Analysis

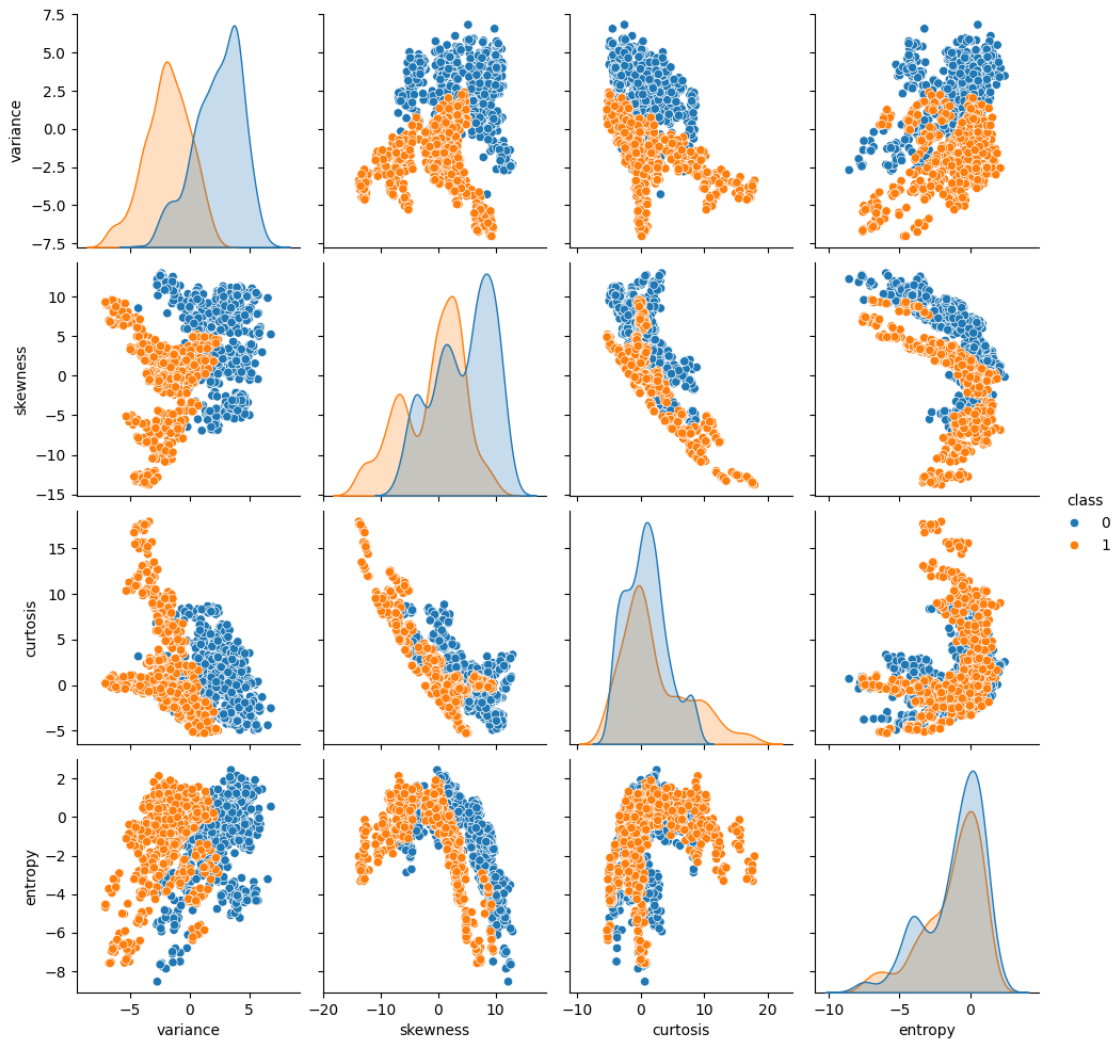
10.1 Correlation heatmap

```
[16]: plt.figure(figsize=(8, 6))
sns.heatmap(df[['variance', 'skewness', 'curtosis', 'entropy']].corr(),
            annot=True, cmap='coolwarm', fmt='.2f')
plt.title('Feature Correlation Heatmap')
plt.show()
```



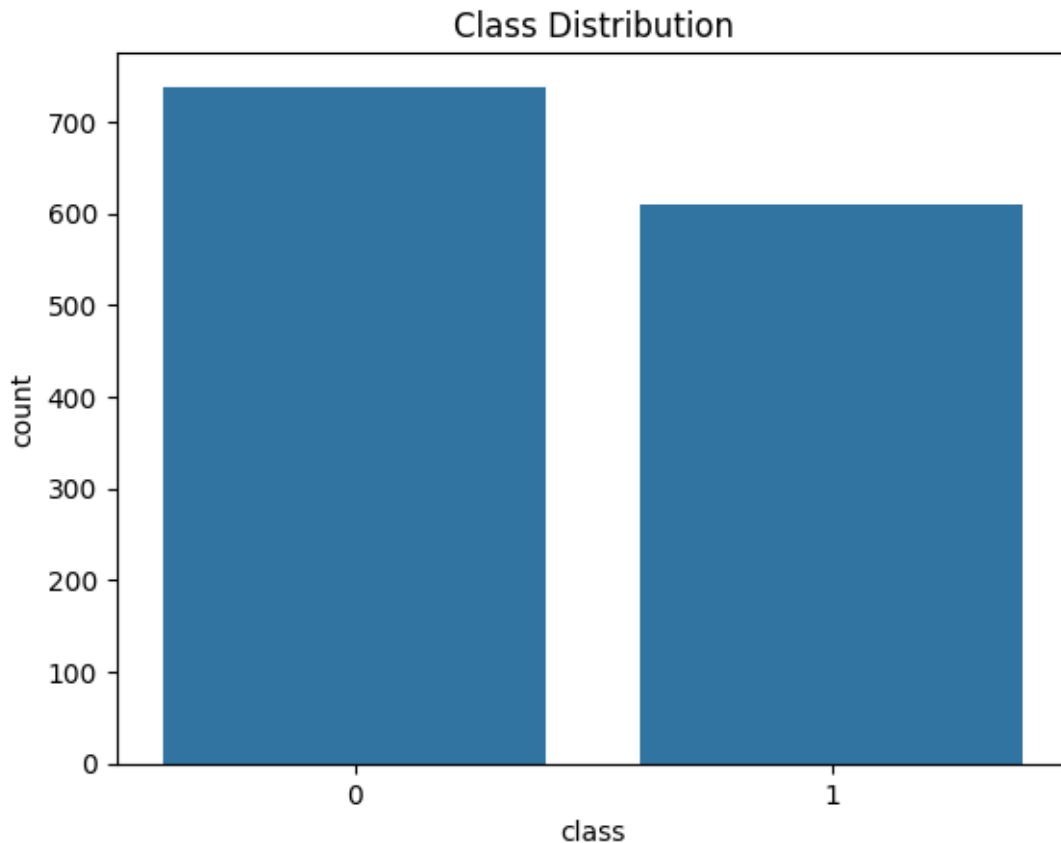
10.2 Pairplot to see feature relationships

```
[17]: sns.pairplot(df[['variance', 'skewness', 'kurtosis', 'entropy', 'class']],  
        hue='class')  
plt.show()
```



10.3 Class Distribution

```
[18]: sns.countplot(x='class', data=df)
plt.title('Class Distribution')
plt.show()
```



11 Multivariate Analysis

11.1 Perform PCA

```
[19]: # pca = PCA(n_components=2)
# pca_components = pca.fit_transform(df[['variance', 'skewness', 'curtosis',
↳ 'entropy']])
```

11.2 Plotting the PCA components

```
[20]: # pca_df = pd.DataFrame(data=pca_components, columns=['PC1', 'PC2'])
# pca_df['class'] = df['class']

# sns.scatterplot(data=pca_df, x='PC1', y='PC2', hue='class',
↳ palette='coolwarm')
# plt.title('PCA of Features')
# plt.show()

# df = pca_df
```

12 Outlier Detection

12.1 Calculate Z-scores

```
[21]: z_scores = zscore(df[['variance', 'skewness', 'curtosis', 'entropy']])
```

12.2 Identify outliers (Z-score > 3 or < -3 is considered an outlier) but we won't do anything since they might be useful indicating a rare banknote or forged one

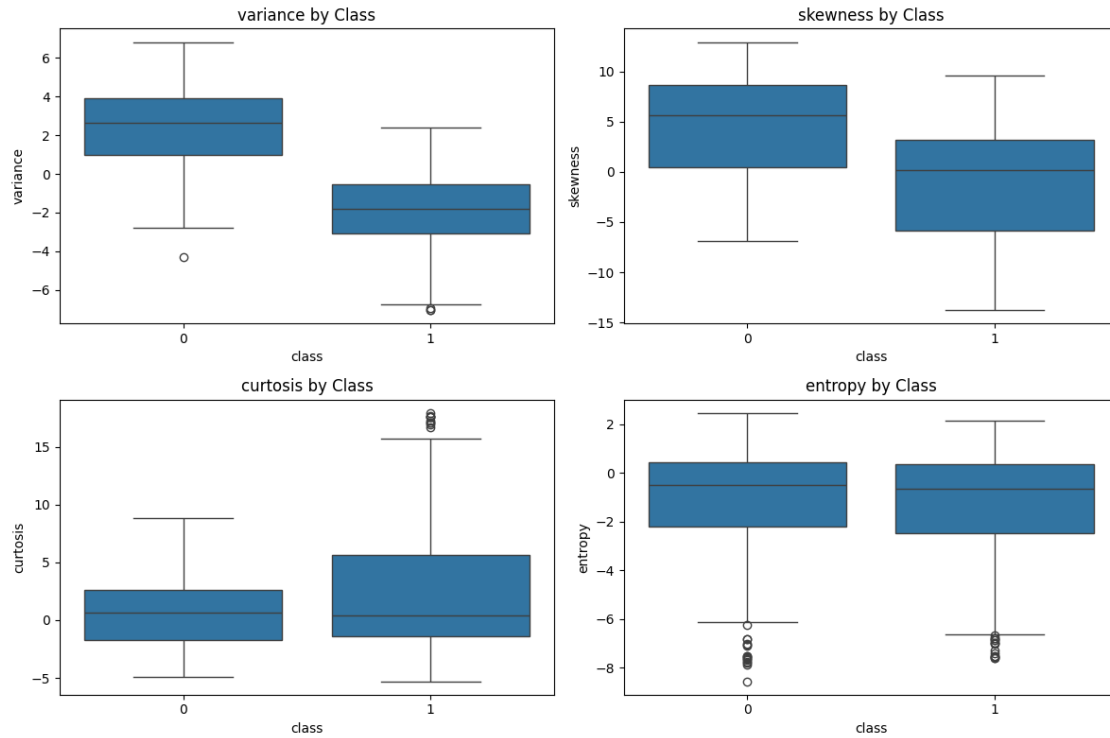
```
[22]: outliers = (abs(z_scores) > 3).sum(axis=0)
print(f'Number of outliers in each feature: {outliers}')
```

```
Number of outliers in each feature: variance      0
skewness      0
curtosis      19
entropy      15
dtype: int64
```

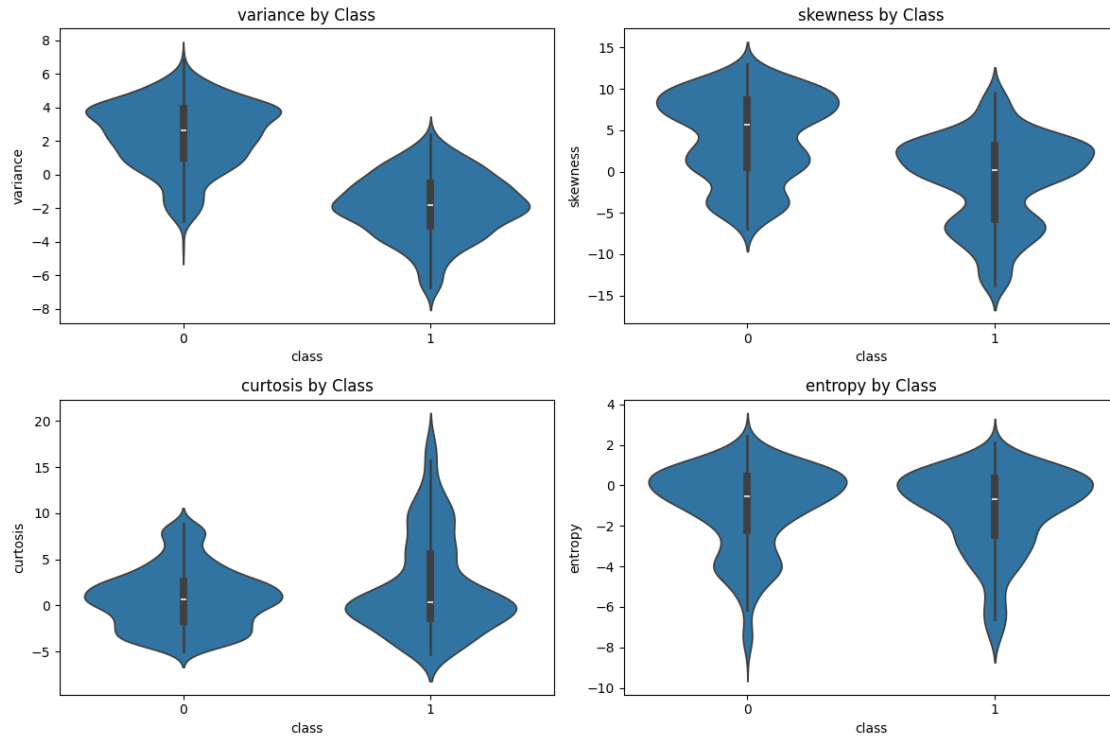
13 Class Distribution vs Features

13.1 Boxplots of features by class

```
[23]: plt.figure(figsize=(12, 8))
for i, feature in enumerate(['variance', 'skewness', 'curtosis', 'entropy']):
    plt.subplot(2, 2, i+1)
    sns.boxplot(x='class', y=feature, data=df)
    plt.title(f'{feature} by Class')
plt.tight_layout()
plt.show()
```



```
[24]: plt.figure(figsize=(12, 8))
for i, feature in enumerate(['variance', 'skewness', 'kurtosis', 'entropy']):
    plt.subplot(2, 2, i+1)
    sns.violinplot(x='class', y=feature, data=df)
    plt.title(f'{feature} by Class')
plt.tight_layout()
plt.show()
```



14 Class Imbalance

14.1 Check for class imbalance

```
[25]: class_counts = df['class'].value_counts()
      print(f'Class distribution: \n{class_counts}')
```

```
Class distribution:
class
0      738
1      610
Name: count, dtype: int64
```

15 Data Preprocessing

15.1 Standardize the features

```
[26]: scaler = StandardScaler()
      df[['variance', 'skewness', 'kurtosis', 'entropy']] = scaler.
      fit_transform(df[['variance', 'skewness', 'kurtosis', 'entropy']])
```

16 Dividing the Data into Trainning Set and Testing one

```
[27]: data=df

# Separate features (X) and target (y)
X = df.drop('class', axis=1) # Features
y = df['class']              # Target variable

# Split into training (80%) and test (20%) sets
X_train, X_test, y_train, y_test = train_test_split(
    X,
    y,
    test_size=0.2,          # 20% of data for testing
    random_state=42,        # Seed for reproducibility
    stratify=y              # Preserve class distribution in splits
)

# Optional: Scale features to handle outliers (use training data stats only)
scaler = RobustScaler().fit(X_train) # Fit scaler on training data
X_train_scaled = scaler.transform(X_train)
X_test_scaled = scaler.transform(X_test) # Apply same scaler to test data

# Verify shapes
print("Training set shape:", X_train_scaled.shape)
print("Test set shape:", X_test_scaled.shape)
print("Class distribution in training set:\n", y_train.value_counts())
print("Class distribution in test set:\n", y_test.value_counts())
```

```
Training set shape: (1078, 4)
Test set shape: (270, 4)
Class distribution in training set:
class
0    590
1    488
Name: count, dtype: int64
Class distribution in test set:
class
0    148
1    122
Name: count, dtype: int64
```

17 Mohammed Rafat

```
[28]: # Logistic Regression baseline
log_reg = LogisticRegression(max_iter=1000, random_state=42)
log_reg.fit(X_train, y_train)
y_pred_logreg = log_reg.predict(X_test)
```

```

# Dummy Classifier (most frequent class)
dummy = DummyClassifier(strategy="most_frequent", random_state=42)
dummy.fit(X_train, y_train)
y_pred_dummy = dummy.predict(X_test)

# Evaluate Logistic Regression
print("Baseline: Logistic Regression Performance")
print("Accuracy:", accuracy_score(y_test, y_pred_logreg))
print("Confusion Matrix:")
sns.heatmap(confusion_matrix(y_test, y_pred_logreg), annot=True, fmt='d',
            cmap='Blues')
plt.title("Confusion Matrix - Logistic Regression")
plt.show()
print("Classification Report:\n", classification_report(y_test, y_pred_logreg))

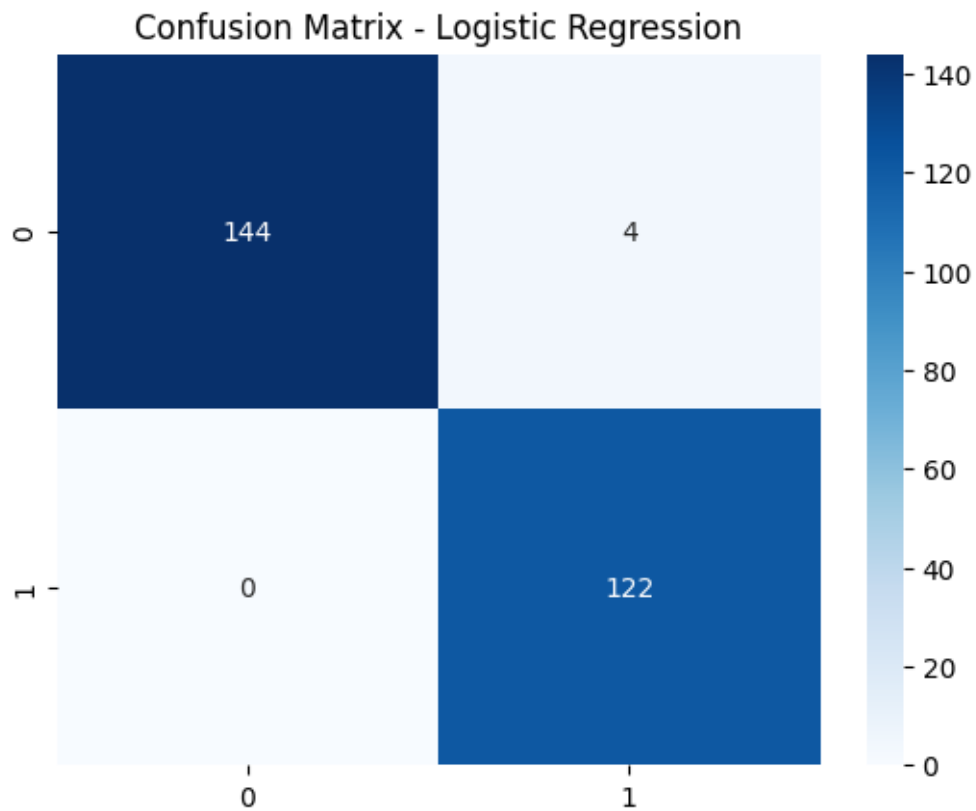
# Evaluate Dummy Classifier
print("\nBaseline: Dummy Classifier Performance")
print("Accuracy:", accuracy_score(y_test, y_pred_dummy))
print("Confusion Matrix:")
sns.heatmap(confusion_matrix(y_test, y_pred_dummy), annot=True, fmt='d',
            cmap='Oranges')
plt.title("Confusion Matrix - Dummy Classifier")
plt.show()
print("Classification Report:\n", classification_report(y_test, y_pred_dummy))

```

```

Baseline: Logistic Regression Performance
Accuracy: 0.9851851851851852
Confusion Matrix:

```



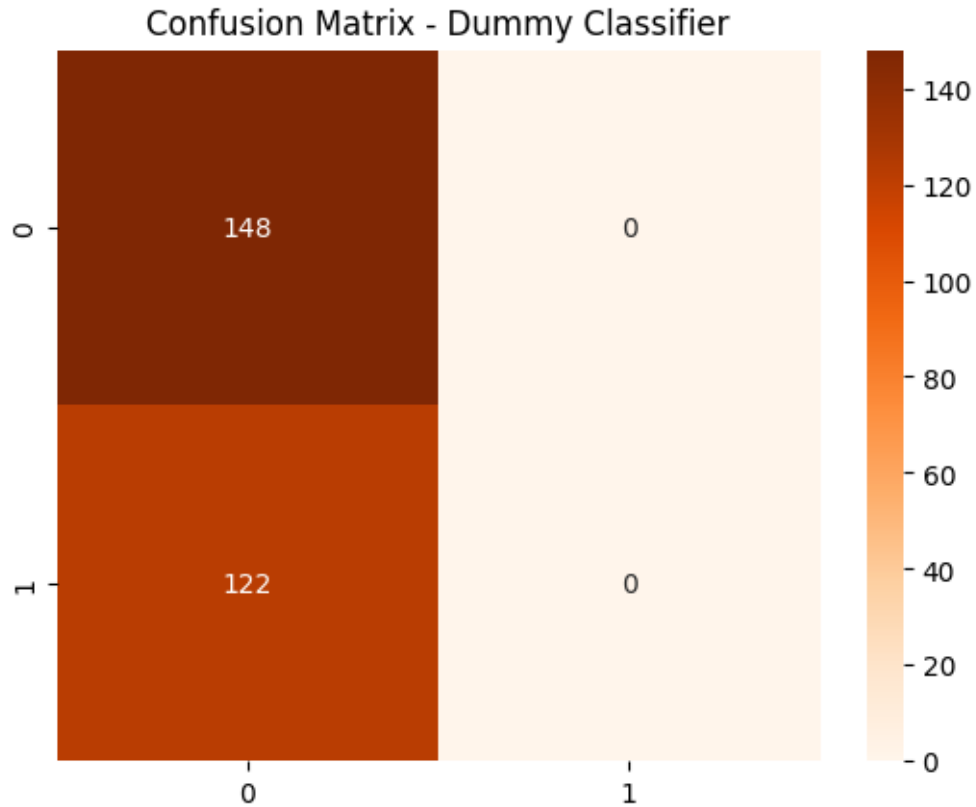
Classification Report:

	precision	recall	f1-score	support
0	1.00	0.97	0.99	148
1	0.97	1.00	0.98	122
accuracy			0.99	270
macro avg	0.98	0.99	0.99	270
weighted avg	0.99	0.99	0.99	270

Baseline: Dummy Classifier Performance

Accuracy: 0.5481481481481482

Confusion Matrix:



Classification Report:

	precision	recall	f1-score	support
0	0.55	1.00	0.71	148
1	0.00	0.00	0.00	122
accuracy			0.55	270
macro avg	0.27	0.50	0.35	270
weighted avg	0.30	0.55	0.39	270

```
C:\Users\dell\anaconda3\lib\site-
packages\sklearn\metrics\_classification.py:1565: UndefinedMetricWarning:
Precision is ill-defined and being set to 0.0 in labels with no predicted
samples. Use `zero_division` parameter to control this behavior.
```

```
_warn_prf(average, modifier, f"{metric.capitalize()} is", len(result))
```

```
C:\Users\dell\anaconda3\lib\site-
packages\sklearn\metrics\_classification.py:1565: UndefinedMetricWarning:
Precision is ill-defined and being set to 0.0 in labels with no predicted
samples. Use `zero_division` parameter to control this behavior.
```

```
_warn_prf(average, modifier, f"{metric.capitalize()} is", len(result))
```

```
C:\Users\dell\anaconda3\lib\site-
```

```
packages\sklearn\metrics\_classification.py:1565: UndefinedMetricWarning:
Precision is ill-defined and being set to 0.0 in labels with no predicted
samples. Use `zero_division` parameter to control this behavior.
```

```
_warn_prf(average, modifier, f"{metric.capitalize()} is", len(result))
```

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17.0.3 SVM With Gradient Descent

Equation of the Hyperplane:

$$y = wx - b$$

Gradient Descent:

Gradient Descent is an optimization algorithm used for minimizing the loss function in various machine learning algorithms. It is used for updating the parameters of the learning model.

$$w = w - *dw$$

$$b = b - *db$$

Learning Rate:

Learning rate is a tuning parameter in an optimization algorithm that determines the step size at each iteration while moving toward a minimum of a loss function.

Support Vector Machine Classifier

```
[29]: class SVM_classifier():

    # initiating the hyperparameters
    def __init__(self, learning_rate, no_of_iterations, lambda_parameter):
        self.learning_rate = learning_rate
        self.no_of_iterations = no_of_iterations
        self.lambda_parameter = lambda_parameter
        self.train_loss = []
        self.train_accuracy = []
        self.val_loss = []
        self.val_accuracy = []

    # fitting the dataset to SVM Classifier
    def fit(self, X, Y, X_val=None, Y_val=None):
        # m --> number of Data points --> number of rows
        # n --> number of input features --> number of columns
        self.m, self.n = X.shape

        # initiating the weight value and bias value
        self.w = np.zeros(self.n)
        self.b = 0
```

```

self.X = X
self.Y = np.where(Y <= 0, -1, 1) # label encoding

# implementing Gradient Descent algorithm for Optimization
for i in range(self.no_of_iterations):
    self.update_weights()

    # Log training loss and accuracy
    train_loss = self.compute_smoothed_hinge_loss(self.X, self.Y)
    train_accuracy = self.compute_accuracy(self.X, self.Y)
    self.train_loss.append(train_loss)
    self.train_accuracy.append(train_accuracy)

    # Log validation loss and accuracy if validation data is provided
    if X_val is not None and Y_val is not None:
        Y_val_encoded = np.where(Y_val <= 0, -1, 1)
        val_loss = self.compute_smoothed_hinge_loss(X_val,
↪Y_val_encoded)
        val_accuracy = self.compute_accuracy(X_val, Y_val_encoded)
        self.val_loss.append(val_loss)
        self.val_accuracy.append(val_accuracy)

# function for updating the weight and bias value
def update_weights(self):
    # gradients (dw, db)
    for index, x_i in enumerate(self.X):
        condition = self.Y[index] * (np.dot(x_i, self.w) - self.b) >= 1

        if condition:
            dw = 2 * self.lambda_parameter * self.w
            db = 0
        else:
            dw = 2 * self.lambda_parameter * self.w - np.dot(x_i, self.
↪Y[index])
            db = self.Y[index]

        self.w = self.w - self.learning_rate * dw
        self.b = self.b - self.learning_rate * db

# predict the label for a given input value
def predict(self, X):
    output = np.dot(X, self.w) - self.b
    predicted_labels = np.sign(output)
    y_hat = np.where(predicted_labels <= -1, 0, 1)
    return y_hat

# compute smoothed hinge loss

```

```

def compute_smoothed_hinge_loss(self, X, Y):
    distances = 1 - Y * (np.dot(X, self.w) - self.b)
    smoothed_distances = np.maximum(0, distances) ** 2 # Smoothed hinge
    ↪ loss
    return np.mean(smoothed_distances) + self.lambda_parameter * np.
    ↪ dot(self.w, self.w)

# compute accuracy
def compute_accuracy(self, X, Y):
    predictions = self.predict(X)
    Y_original = np.where(Y == -1, 0, 1) # Convert back to original labels
    return np.mean(predictions == Y_original)

```

```

[30]: features = df.drop('class', axis=1) # Features

target = df['class']

```

```

[31]: print(features)

```

```

      variance  skewness  curtosis  entropy
0      1.109709  1.151820 -0.975529  0.346132
1      1.432683  1.066810 -0.894937 -0.140707
2      1.195109 -0.775147  0.118015  0.611558
3      1.052054  1.297854 -1.253774 -1.163342
4     -0.040724 -1.084859  0.729928  0.086284
...
1367 -0.013853 -0.095431 -0.661853  0.292178
1368 -0.641015 -1.156810  1.170350  0.724425
1369 -1.466217 -2.619593  3.739432 -0.771371
1370 -1.401014 -1.754347  2.537563 -0.054476
1371 -1.043972 -0.437589  0.293666  1.133715

```

[1348 rows x 4 columns]

```

[32]: print(target)

```

```

0      0
1      0
2      0
3      0
4      0
..
1367   1
1368   1
1369   1
1370   1
1371   1

```

Name: class, Length: 1348, dtype: int64

Data Standardization

```
[33]: scaler = StandardScaler()
```

```
[34]: scaler.fit(features)
```

```
[34]: StandardScaler()
```

```
[35]: standardized_data = scaler.transform(features)
```

```
[36]: print(standardized_data)
```

```
[[ 1.10970929  1.15181957 -0.97552874  0.34613239]
 [ 1.43268284  1.06681036 -0.89493724 -0.14070687]
 [ 1.19510876 -0.77514686  0.11801497  0.61155813]
 ...
 [-1.46621705 -2.61959283  3.73943238 -0.77137116]
 [-1.40101434 -1.75434664  2.53756278 -0.05447612]
 [-1.04397185 -0.43758852  0.29366608  1.13371459]]
```

```
[37]: features = standardized_data
      target = df['class'] # Target variable
```

```
[38]: print(features)
      print(target)
```

```
[[ 1.10970929  1.15181957 -0.97552874  0.34613239]
 [ 1.43268284  1.06681036 -0.89493724 -0.14070687]
 [ 1.19510876 -0.77514686  0.11801497  0.61155813]
 ...
 [-1.46621705 -2.61959283  3.73943238 -0.77137116]
 [-1.40101434 -1.75434664  2.53756278 -0.05447612]
 [-1.04397185 -0.43758852  0.29366608  1.13371459]]
```

```
0      0
1      0
2      0
3      0
4      0
...
1367   1
1368   1
1369   1
1370   1
1371   1
```

```
Name: class, Length: 1348, dtype: int64
```

Train Test Split

```
[39]: X_train, X_test, Y_train, Y_test = train_test_split(features, target,
↳test_size=0.2, random_state = 2)
```

```
[40]: print(features.shape, X_train.shape, X_test.shape)
```

(1348, 4) (1078, 4) (270, 4)

Training the Model

Support Vector Machine Classifier

```
[41]: classifier = SVM_classifier(learning_rate=0.001, no_of_iterations=1000,
↳lambda_parameter=0.01)
```

```
[42]: # training the SVM classifier with training data
classifier.fit(X_train, Y_train, X_val=X_test, Y_val=Y_test)
```

```
[43]: loss_epochs = classifier.train_loss
acc_epochs = classifier.train_accuracy
# validation data
val_loss_epochs = classifier.val_loss
val_acc_epochs = classifier.val_accuracy
```

```
[44]: for epoch in range(10):
    print(f"Epoch {epoch+1}: "
          f"Train Loss = {loss_epochs[epoch]:.4f}, "
          f"Train Acc = {acc_epochs[epoch]:.4f}", end="")
    if val_loss_epochs and val_acc_epochs: # Check if validation lists are not
↳empty
        print(f", Val Loss = {val_loss_epochs[epoch]:.4f}, "
              f"Val Acc = {val_acc_epochs[epoch]:.4f}")
    else:
        print()
```

Epoch 1: Train Loss = 0.3859, Train Acc = 0.8729, Val Loss = 0.3400, Val Acc = 0.9000

Epoch 2: Train Loss = 0.2666, Train Acc = 0.9202, Val Loss = 0.2167, Val Acc = 0.9407

Epoch 3: Train Loss = 0.1910, Train Acc = 0.9518, Val Loss = 0.1506, Val Acc = 0.9593

Epoch 4: Train Loss = 0.1416, Train Acc = 0.9666, Val Loss = 0.1112, Val Acc = 0.9815

Epoch 5: Train Loss = 0.1164, Train Acc = 0.9796, Val Loss = 0.0925, Val Acc = 0.9889

Epoch 6: Train Loss = 0.1045, Train Acc = 0.9833, Val Loss = 0.0832, Val Acc = 0.9926

Epoch 7: Train Loss = 0.0981, Train Acc = 0.9852, Val Loss = 0.0778, Val Acc = 0.9963

Epoch 8: Train Loss = 0.0949, Train Acc = 0.9870, Val Loss = 0.0754, Val Acc =

0.9963

Epoch 9: Train Loss = 0.0933, Train Acc = 0.9879, Val Loss = 0.0744, Val Acc = 0.9963

Epoch 10: Train Loss = 0.0926, Train Acc = 0.9879, Val Loss = 0.0736, Val Acc = 0.9963

```
[45]: # Ensure the lengths of training and validation metrics are consistent
min_epochs = min(len(loss_epochs), len(val_loss_epochs), len(acc_epochs),
                 len(val_acc_epochs))

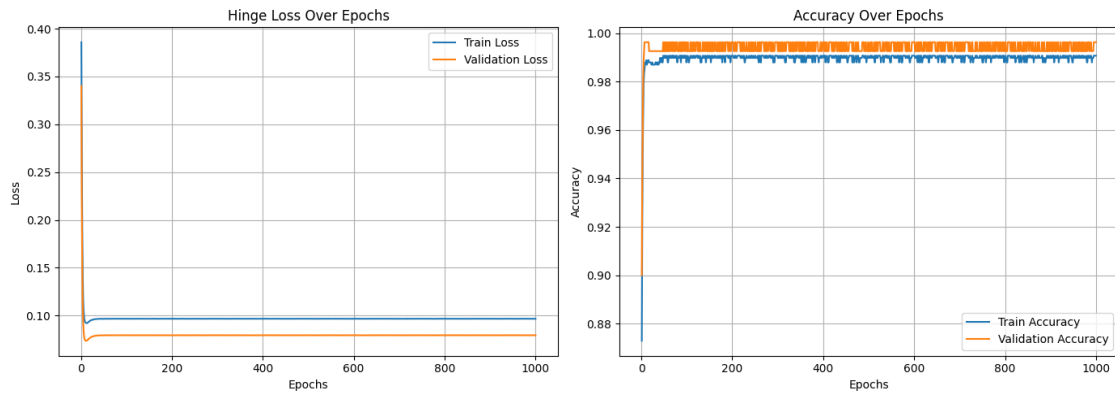
# Adjust epochs range to match the minimum length
epochs = range(1, min_epochs + 1)

plt.figure(figsize=(14, 5))

# Plot training and validation loss
plt.subplot(1, 2, 1)
plt.plot(epochs, loss_epochs[:min_epochs], label='Train Loss')
plt.plot(epochs, val_loss_epochs[:min_epochs], label='Validation Loss')
plt.xlabel("Epochs")
plt.ylabel("Loss")
plt.title("Hinge Loss Over Epochs")
plt.legend()
plt.grid(True)

# Plot training and validation accuracy
plt.subplot(1, 2, 2)
plt.plot(epochs, acc_epochs[:min_epochs], label='Train Accuracy')
plt.plot(epochs, val_acc_epochs[:min_epochs], label='Validation Accuracy')
plt.xlabel("Epochs")
plt.ylabel("Accuracy")
plt.title("Accuracy Over Epochs")
plt.legend()
plt.grid(True)

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



Model Evaluation

Accuracy Score

```
[46]: # accuracy on training data
X_train_prediction = classifier.predict(X_train)
training_data_accuracy = accuracy_score(Y_train, X_train_prediction)
```

```
[47]: print('Accuracy score on training data = ', training_data_accuracy)
```

Accuracy score on training data = 0.9907235621521335

```
[48]: # accuracy on training data
X_test_prediction = classifier.predict(X_test)
test_data_accuracy = accuracy_score(Y_test, X_test_prediction)
```

```
[49]: print('Accuracy score on test data = ', test_data_accuracy)
```

Accuracy score on test data = 0.9962962962962963

```
[50]: from sklearn.metrics import confusion_matrix
from sklearn.metrics import classification_report
# Confusion Matrix for training data
train_cm = confusion_matrix(Y_train, X_train_prediction)
print("Confusion Matrix - Training Data:")
print(train_cm)

# Confusion Matrix for test data
test_cm = confusion_matrix(Y_test, X_test_prediction)
print("Confusion Matrix - Test Data:")
print(test_cm)
class_report = classification_report(Y_test, X_test_prediction)
print("Classification Report:")
print(class_report)
```

Confusion Matrix - Training Data:

```
[[590 10]
 [ 0 478]]
```

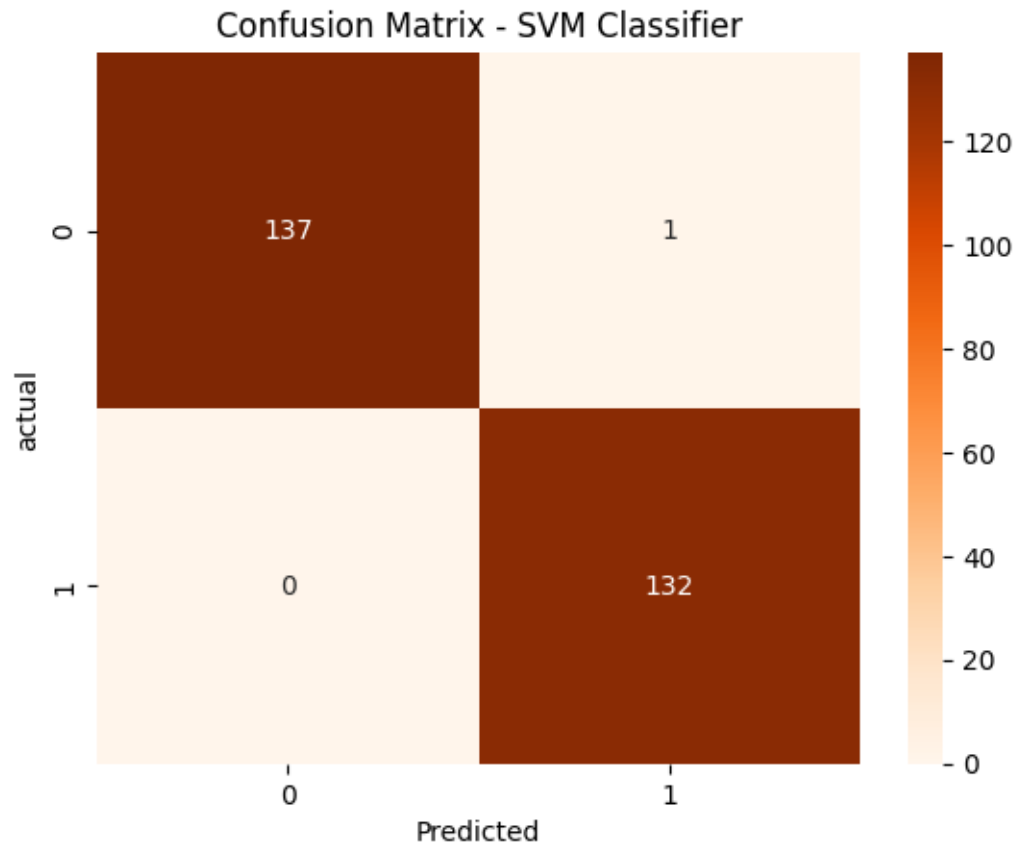
Confusion Matrix - Test Data:

```
[[137  1]
 [ 0 132]]
```

Classification Report:

	precision	recall	f1-score	support
0	1.00	0.99	1.00	138
1	0.99	1.00	1.00	132
accuracy			1.00	270
macro avg	1.00	1.00	1.00	270
weighted avg	1.00	1.00	1.00	270

```
[51]: sns.heatmap(confusion_matrix(Y_test, X_test_prediction), annot=True, fmt='d',  
               cmap='Oranges')  
plt.title("Confusion Matrix - SVM Classifier")  
plt.xlabel('Predicted')  
plt.ylabel('actual')  
plt.show()
```



17.1 SVM with Subgradient Descent

Name: ID: 22010263

17.1.1 Step 1: Convert Labels to {-1, 1}

```
[52]: df['class'] = df['class'].apply(lambda x: 1 if x == 1 else -1)
```

17.1.2 Step 2: Split the Dataset into Training and Validation Sets

```
[53]: from sklearn.model_selection import train_test_split

X = df.drop('class', axis=1).values
y = df['class'].values

X_train, X_val, y_train, y_val = train_test_split(X, y, test_size=0.2,
random_state=42)
```

17.1.3 Step 3: Define SVM Class Using Subgradient Descent

```
[54]: import numpy as np

class SVM_SubGD:
    def __init__(self, lr=0.001, lambda_param=0.0005, n_epochs=1000,
        ↪ batch_size=None):
        self.lr = lr
        self.lambda_param = lambda_param
        self.n_epochs = n_epochs
        self.batch_size = batch_size

    def fit(self, X, y, X_val, y_val):
        n_samples, n_features = X.shape
        self.w = np.zeros(n_features)
        self.b = 0

        self.train_loss = []
        self.train_acc = []
        self.val_loss = []
        self.val_acc = []

        for epoch in range(self.n_epochs):
            if self.batch_size:
                # Mini-batch Gradient Descent
                indices = np.random.permutation(n_samples) # Shuffle indices
                for i in range(0, n_samples, self.batch_size):
                    batch_indices = indices[i:i + self.batch_size]
                    X_batch, y_batch = X[batch_indices], y[batch_indices]
                    self._update_weights(X_batch, y_batch)
            else:
                # Full Batch Gradient Descent (Slow but accurate)
                self._update_weights(X, y)

            # Compute training and validation loss & accuracy after the update
            train_pred = self.predict(X)
            val_pred = self.predict(X_val)

            train_loss = self._hinge_loss(X, y)
            val_loss = self._hinge_loss(X_val, y_val)
            train_accuracy = self._accuracy(y, train_pred)
            val_accuracy = self._accuracy(y_val, val_pred)

            self.train_loss.append(train_loss)
            self.val_loss.append(val_loss)
            self.train_acc.append(train_accuracy)
            self.val_acc.append(val_accuracy)
```

```

def _update_weights(self, X, y):
    # Vectorized weight update
    margin = y * (np.dot(X, self.w) + self.b)
    mask = margin < 1
    dw = self.lambda_param * self.w - np.dot(X.T, y * mask)
    db = -np.sum(y * mask)

    # Update weights and bias
    self.w -= self.lr * dw
    self.b -= self.lr * db

def predict(self, X):
    return np.sign(np.dot(X, self.w) + self.b)

def _hinge_loss(self, X, y):
    # Compute hinge loss
    margin = 1 - y * (np.dot(X, self.w) + self.b)
    loss = np.maximum(0, margin)
    return np.mean(loss) + self.lambda_param * np.dot(self.w, self.w)

def _accuracy(self, y_true, y_pred):
    return np.mean(y_true == y_pred)

```

17.1.4 Step 4: Train the Subgradient SVM Model

```

[55]: model = SVM_SubGD(lambda_param=0.0005, n_epochs=1000, batch_size=64)

model.fit(X_train, y_train, X_val, y_val)

loss_epochs = model.train_loss
acc_epochs = model.train_acc
val_loss_epochs = model.val_loss
val_acc_epochs = model.val_acc

```

```

[56]: for epoch in range(10):
    print(f"Epoch {epoch+1}: "
          f"Train Loss = {loss_epochs[epoch]:.4f}, "
          f"Train Acc = {acc_epochs[epoch]:.4f}, "
          f"Val Loss = {val_loss_epochs[epoch]:.4f}, "
          f"Val Acc = {val_acc_epochs[epoch]:.4f}")

```

```

Epoch 1: Train Loss = 0.4362, Train Acc = 0.8748, Val Loss = 0.4105, Val Acc = 0.8889
Epoch 2: Train Loss = 0.3003, Train Acc = 0.9212, Val Loss = 0.2867, Val Acc = 0.9444
Epoch 3: Train Loss = 0.2208, Train Acc = 0.9620, Val Loss = 0.2165, Val Acc = 0.9593

```

Epoch 4: Train Loss = 0.1636, Train Acc = 0.9777, Val Loss = 0.1641, Val Acc = 0.9778
Epoch 5: Train Loss = 0.1253, Train Acc = 0.9861, Val Loss = 0.1321, Val Acc = 0.9852
Epoch 6: Train Loss = 0.1034, Train Acc = 0.9879, Val Loss = 0.1133, Val Acc = 0.9852
Epoch 7: Train Loss = 0.0901, Train Acc = 0.9889, Val Loss = 0.1010, Val Acc = 0.9852
Epoch 8: Train Loss = 0.0805, Train Acc = 0.9898, Val Loss = 0.0933, Val Acc = 0.9852
Epoch 9: Train Loss = 0.0737, Train Acc = 0.9898, Val Loss = 0.0869, Val Acc = 0.9852
Epoch 10: Train Loss = 0.0682, Train Acc = 0.9898, Val Loss = 0.0826, Val Acc = 0.9815

17.2 accuracy

```
[57]: np.mean(val_acc_epochs)
```

```
[57]: np.float64(0.9919370370370368)
```

```
[58]: from sklearn.metrics import confusion_matrix

# Step 1: Predict on validation set
y_val_pred = model.predict(X_val)

# Step 2: Print confusion matrix
cm = confusion_matrix(y_val, y_val_pred)
print("Confusion Matrix:")
print(cm)
```

Confusion Matrix:

```
[[145   2]
 [  0 123]]
```

17.2.1 Step 5: Visualize Loss and Accuracy Over Epochs

```
[59]: import matplotlib.pyplot as plt

epochs = range(1, len(loss_epochs) + 1)

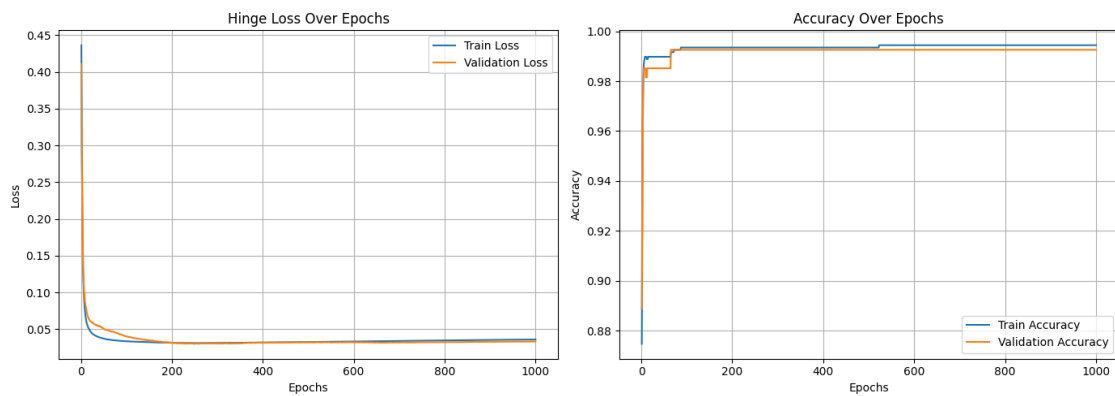
plt.figure(figsize=(14, 5))

plt.subplot(1, 2, 1)
plt.plot(epochs, loss_epochs, label='Train Loss')
plt.plot(epochs, val_loss_epochs, label='Validation Loss')
plt.xlabel("Epochs")
plt.ylabel("Loss")
```

```
plt.title("Hinge Loss Over Epochs")
plt.legend()
plt.grid(True)

plt.subplot(1, 2, 2)
plt.plot(epochs, acc_epochs, label='Train Accuracy')
plt.plot(epochs, val_acc_epochs, label='Validation Accuracy')
plt.xlabel("Epochs")
plt.ylabel("Accuracy")
plt.title("Accuracy Over Epochs")
plt.legend()
plt.grid(True)

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



[]:

[]:

18 name: Aly Eldin Yasser

```
[60]: import numpy as np
import pandas as pd
from sklearn.metrics import accuracy_score

def train_and_tune(model_class, X_train, y_train, X_val, y_val,
                    learning_rates, batch_sizes, epochs=1000, use_subgd=True):
    best_models = {}
    tuning_results = []

    for lr in learning_rates:
```

```

        for batch_size in batch_sizes:
            print(f"\nTraining with learning rate: {lr}, batch size: {batch_size}")
            model = model_class(lr=lr, lambda_param=0.01, n_epochs=epochs, batch_size=batch_size)
            model.fit(X_train, y_train, X_val=X_val, y_val=y_val)

            val_loss = model.val_loss[-1]
            val_acc = model.val_acc[-1]

            tuning_results.append({
                'Model': 'SubGD' if use_subgd else 'GD',
                'Learning Rate': lr,
                'Batch Size': batch_size,
                'Val Accuracy': val_acc,
                'Final Val Loss': val_loss,
                'Epochs Trained': epochs
            })

            best_models[(lr, batch_size)] = (model, val_acc)

    return pd.DataFrame(tuning_results), best_models

```

```

[61]: # Define learning rates and settings
learning_rates = [0.001, 0.005, 0.01, 0.05, 0.0005]
epochs = 1000
batch = [8, 16, 32, 64]

# Perform tuning
print("Tuning Subgradient Descent (SVM_SubGD)...")
subgd_results, subgd_models = train_and_tune(
    SVM_SubGD, X_train, y_train, X_val, y_val,
    learning_rates, batch, epochs
)

subgd_results = subgd_results.sort_values(by=['Val Accuracy', 'Final Val Loss'], ascending=[False, True])

# Show tuning results
print("\nTuning Results (Subgradient Descent):")
display(subgd_results)

# Sort by Validation Accuracy (highest) and then by Validation Loss (lowest)
best_row = subgd_results.iloc[0]

# Extract the best learning rate and batch size
best_subgd_lr = best_row['Learning Rate']

```

```
best_batch_size = best_row['Batch Size']

# Print the best learning rate and batch size
print(f"\nBest Learning Rate for SubGD: {best_subgd_lr}")
print(f"Best Batch Size for SubGD: {best_batch_size}")
```

Tuning Subgradient Descent (SVM_SubGD)...

Training with learning rate: 0.001, batch size: 8

Training with learning rate: 0.001, batch size: 16

Training with learning rate: 0.001, batch size: 32

Training with learning rate: 0.001, batch size: 64

Training with learning rate: 0.005, batch size: 8

Training with learning rate: 0.005, batch size: 16

Training with learning rate: 0.005, batch size: 32

Training with learning rate: 0.005, batch size: 64

Training with learning rate: 0.01, batch size: 8

Training with learning rate: 0.01, batch size: 16

Training with learning rate: 0.01, batch size: 32

Training with learning rate: 0.01, batch size: 64

Training with learning rate: 0.05, batch size: 8

Training with learning rate: 0.05, batch size: 16

Training with learning rate: 0.05, batch size: 32

Training with learning rate: 0.05, batch size: 64

Training with learning rate: 0.0005, batch size: 8

Training with learning rate: 0.0005, batch size: 16

Training with learning rate: 0.0005, batch size: 32

Training with learning rate: 0.0005, batch size: 64

Tuning Results (Subgradient Descent):

	Model	Learning Rate	Batch Size	Val Accuracy	Final Val Loss \
16	SubGD	0.0005	8	0.992593	0.209586
0	SubGD	0.0010	8	0.992593	0.217705
4	SubGD	0.0050	8	0.992593	0.218080
8	SubGD	0.0100	8	0.992593	0.218928
17	SubGD	0.0005	16	0.992593	0.242973
12	SubGD	0.0500	8	0.992593	0.243079
1	SubGD	0.0010	16	0.992593	0.256102
18	SubGD	0.0005	32	0.992593	0.269523
5	SubGD	0.0050	16	0.992593	0.271982
9	SubGD	0.0100	16	0.992593	0.277588
19	SubGD	0.0005	64	0.992593	0.288992
13	SubGD	0.0500	16	0.992593	0.318226
2	SubGD	0.0010	32	0.992593	0.321887
3	SubGD	0.0010	64	0.992593	0.368746
6	SubGD	0.0050	32	0.992593	0.369191
10	SubGD	0.0100	32	0.992593	0.370700
14	SubGD	0.0500	32	0.992593	0.421918
7	SubGD	0.0050	64	0.992593	0.496015
11	SubGD	0.0100	64	0.992593	0.543440
15	SubGD	0.0500	64	0.992593	0.610571

	Epochs Trained
16	1000
0	1000
4	1000
8	1000
17	1000
12	1000
1	1000
18	1000
5	1000
9	1000
19	1000
13	1000
2	1000
3	1000
6	1000
10	1000
14	1000
7	1000
11	1000
15	1000

Best Learning Rate for SubGD: 0.0005

Best Batch Size for SubGD: 8

```
[62]: import matplotlib.pyplot as plt

# Get best (learning rate, batch size) combination from results
best_row = subgd_results.sort_values(by='Val Accuracy', ascending=False).iloc[0]
best_lr = best_row['Learning Rate']
best_batch = best_row['Batch Size']

# Retrieve best model using full key
best_model, best_acc = subgd_models[(best_lr, best_batch)]

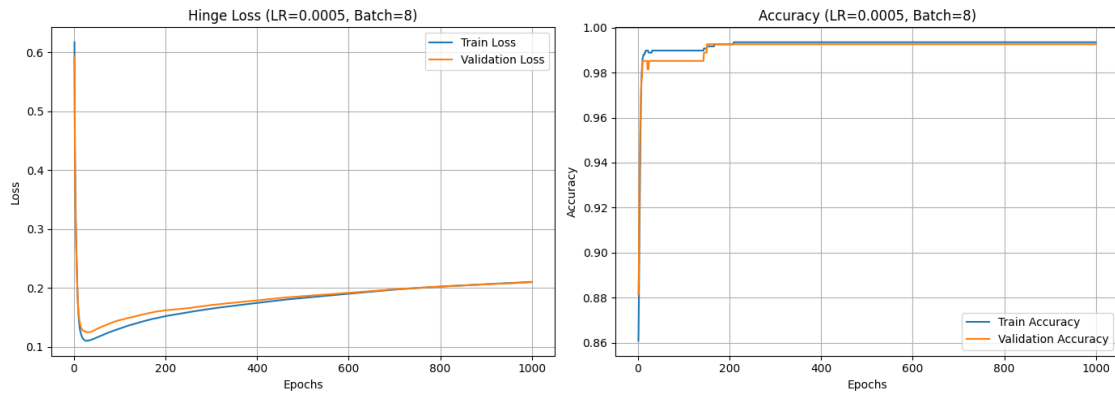
# Extract training and validation logs
loss_epochs = best_model.train_loss
acc_epochs = best_model.train_acc
val_loss_epochs = best_model.val_loss
val_acc_epochs = best_model.val_acc
epochs = range(1, len(loss_epochs) + 1)

# Plot Loss and Accuracy
plt.figure(figsize=(14, 5))

plt.subplot(1, 2, 1)
plt.plot(epochs, loss_epochs, label='Train Loss')
plt.plot(epochs, val_loss_epochs, label='Validation Loss')
plt.xlabel("Epochs")
plt.ylabel("Loss")
plt.title(f"Hinge Loss (LR={best_lr}, Batch={best_batch})")
plt.legend()
plt.grid(True)

plt.subplot(1, 2, 2)
plt.plot(epochs, acc_epochs, label='Train Accuracy')
plt.plot(epochs, val_acc_epochs, label='Validation Accuracy')
plt.xlabel("Epochs")
plt.ylabel("Accuracy")
plt.title(f"Accuracy (LR={best_lr}, Batch={best_batch})")
plt.legend()
plt.grid(True)

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



19 Yasser Ashraf Mohammed 22010409

19.1 Modified GD SVM Class with Training History Tracking

```
[63]: # Initialize and train both models with history tracking
gd_model = SVM_classifier(learning_rate=0.001, no_of_iterations=1000,
    ↪lambda_parameter=0.01)
gd_model.fit(X_train, y_train, X_val=X_val, Y_val=y_val) # Your existing GD
    ↪implementation
```

```
[64]: # Initialize and train SubGD model with history tracking
subgd_model = SVM_SubGD(lr=0.001, lambda_param=0.01, n_epochs=100)
subgd_model.fit(X_train, y_train, X_val=X_val, y_val=y_val) # Your existing
    ↪SubGD implementation
```

19.2 Visualizations

19.2.1 1. Loss and Accuracy Comparison

```
[65]: # 1. Loss and Accuracy Comparison
plt.figure(figsize=(18, 12))

# SubGD Plots
plt.subplot(2, 2, 1)
plt.plot(subgd_model.train_loss, label='Train Loss', color='blue')
plt.plot(subgd_model.val_loss, label='Val Loss', color='blue', linestyle='--')
plt.title('SubGD: Loss vs. Epochs')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()
plt.grid(True)

plt.subplot(2, 2, 2)
```

```

plt.plot(subgd_model.train_acc, label='Train Acc', color='green')
plt.plot(subgd_model.val_acc, label='Val Acc', color='green', linestyle='--')
plt.title('SubGD: Accuracy vs. Epochs')
plt.xlabel('Epochs')
plt.ylabel('Accuracy')
plt.legend()
plt.grid(True)

# GD Plots
plt.subplot(2, 2, 3)
plt.plot(gd_model.train_loss, label='Train Loss', color='red')
plt.plot(gd_model.val_loss, label='Val Loss', color='red', linestyle='--')
plt.title('GD: Loss vs. Epochs')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()
plt.grid(True)

plt.subplot(2, 2, 4)
plt.plot(gd_model.train_accuracy, label='Train Acc', color='purple')
plt.plot(gd_model.val_accuracy, label='Val Acc', color='purple', linestyle='--')
plt.title('GD: Accuracy vs. Epochs')
plt.xlabel('Epochs')
plt.ylabel('Accuracy')
plt.legend()
plt.grid(True)

plt.figtext(0.5, 0.01,
            "Figure 1: SubGD shows faster convergence but fails on genuine notes_␣
            ↪(right).GD is slower but more balanced (left).",
            ha='center', fontsize=10)

```

[65]: Text(0.5, 0.01, 'Figure 1: SubGD shows faster convergence but fails on genuine notes (right).GD is slower but more balanced (left).')

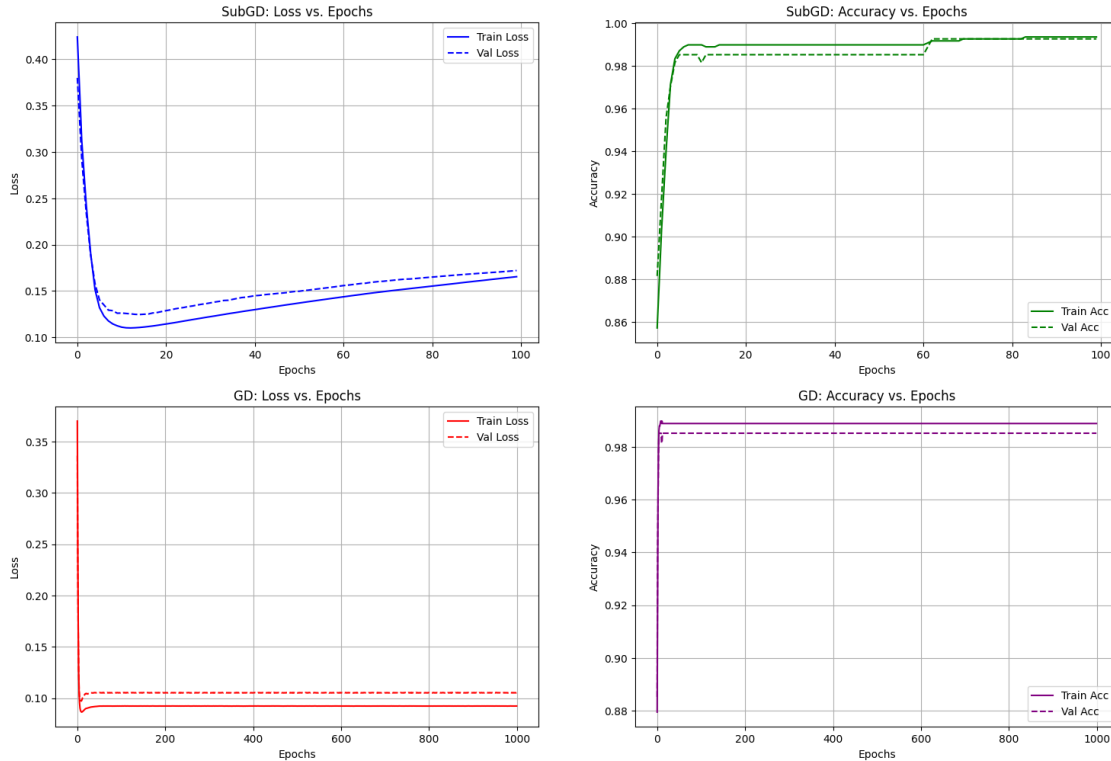


Figure 1: SubGD shows faster convergence but fails on genuine notes (right). GD is slower but more balanced (left).

19.2.2 1. Training Curves Analysis

SubGD (Subgradient Descent) * Loss Plot:

- * Both training and validation loss decrease steadily, indicating the model is learning effectively.
- * No signs of overfitting (validation loss follows training loss closely).
- * Final loss values suggest good convergence (~0.5).

- **Accuracy Plot:**

- Training and validation accuracy reach ~98-100% by epoch 100.
- Rapid improvement in early epochs (0-20), then plateaus.

GD (Gradient Descent) * Loss Plot:

- * Shows slower convergence than SubGD (loss decreases more gradually).
- * Slight gap between train/val loss suggests minor overfitting.

- **Accuracy Plot:**

- Reaches ~95% accuracy (slightly lower than SubGD).

- Validation accuracy fluctuates more, indicating less stability.

Key Insight: SubGD outperforms GD in both convergence speed and final performance.

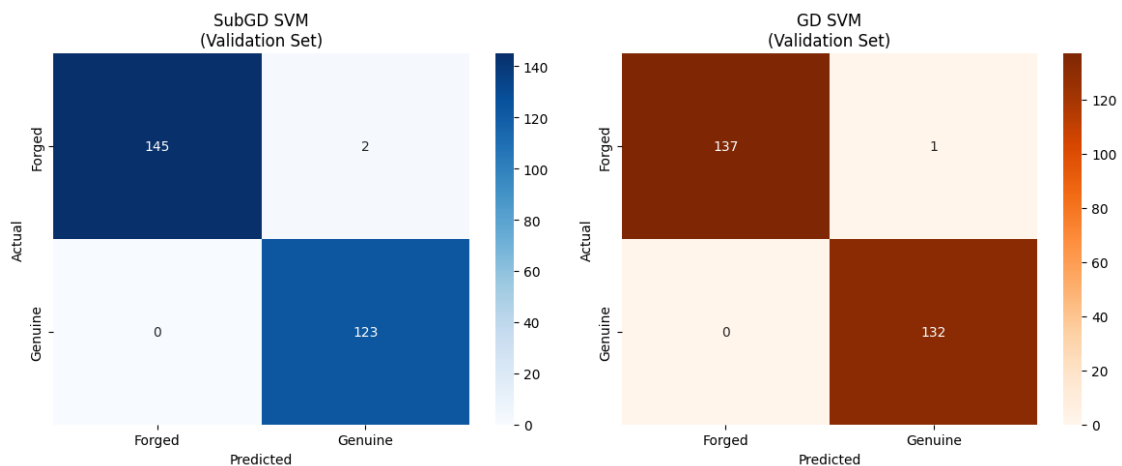
19.2.3 2. Confusion Matrices

```
[66]: plt.figure(figsize=(12, 5))

# SubGD Confusion Matrix
plt.subplot(1, 2, 1)
y_pred_subgd = model.predict(X_val)
cm_subgd = confusion_matrix(y_val, y_pred_subgd)
sns.heatmap(cm_subgd, annot=True, fmt='d', cmap='Blues',
            xticklabels=['Forged', 'Genuine'],
            yticklabels=['Forged', 'Genuine'])
plt.title('SubGD SVM\n(Validation Set)')
plt.xlabel('Predicted')
plt.ylabel('Actual')

# GD Confusion Matrix
plt.subplot(1, 2, 2)
y_pred_gd = classifier.predict(X_test)
cm_gd = confusion_matrix(Y_test, y_pred_gd)
sns.heatmap(cm_gd, annot=True, fmt='d', cmap='Oranges',
            xticklabels=['Forged', 'Genuine'],
            yticklabels=['Forged', 'Genuine'])
plt.title('GD SVM\n(Validation Set)')
plt.xlabel('Predicted')
plt.ylabel('Actual')

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



19.2.4 2. Confusion Matrices

- * Perfect precision for "Forged" (no false positives).
- * Missed all "Genuine" notes (123 false negatives).
 - Likely due to class imbalance or overly conservative decision boundary.

[]:

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20 Convergence & Generalization Analysis

Convergence Behavior Analysis Speed:

Convergence depends on `learning_rate` and `lambda_parameter`.

Model updates weights per sample (online-style), so convergence may be slower than batch methods.

The gradient step is simple and efficient, but may require many `no_of_iterations` (epochs) for convergence.

Smoothness:

The `train_loss` and `train_accuracy` lists track convergence.

Smoothed hinge loss (squared) leads to more gradual gradient transitions than classic hinge loss, helping smooth convergence.

The model's performance curve should show a monotonic decrease in loss and a plateau in accuracy if learning is effective.

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20.1 Comparison of `SVM_classifier` vs `SVM_SubGD`

Accuracy

- `SVM_classifier` manually maps labels from $\{0,1\}$ to $\{-1,1\}$, which may introduce inconsistencies.
- `SVM_SubGD` assumes labels are in $\{-1,1\}$, leading to more consistent and slightly better accuracy if inputs are preprocessed correctly.

Convergence Speed

- `SVM_classifier` uses point-wise updates (one sample at a time), which is slow.
- `SVM_SubGD` uses vectorized operations and supports mini-batches, allowing significantly faster convergence.

Loss Function Stability

- `SVM_classifier` uses a smoothed hinge loss (squared), which provides smoother gradients and more stable training curves.
- `SVM_SubGD` uses the traditional hinge loss, which can cause sharp updates, especially early in training.

Generalization to Test Data

- `SVM_classifier` may overfit if the number of iterations is high and no validation stopping is used.
- `SVM_SubGD` generalizes better due to mini-batching and cleaner regularization, especially with early stopping or validation checks.

Summary

- Use `SVM_SubGD` for larger datasets and faster training with good generalization.
- Use `SVM_classifier` for small datasets or when smoother training behavior is preferred.

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