

Ravi Teja Kothuru_Final Project AAI-510 Section IN2-Team 14

June 21, 2025

1 Final Team Project - Group 14

- **Name:** Ravi Teja Kothuru
- **Course Code:** AAI-510-IN2
- **Course Name:** Machine learning: Fundamentals and Applications
- University of San Diego
- **Instructor:** Dr. Raj Kumar Garg
- **Date:** 23rd June 2025

2 Project Details

- **Title of the Project:** Unspoken Signals: Voice-Based AI to Decode Emotions

- **Description and Objectives of the Project:**

- Thoughts and feelings are shared between humans not only through verbal language but also through the nuanced variations of human vocalization - variations in emphasis (tone), loudness (energy), pitch, and timing (rhythm) - signals that machines are often not adept at interpreting. While machines have become remarkably more intelligent, our capabilities for perceiving and interpreting the emotional aspects of spoken human language remain far behind technology. This is highly relevant when developing empathetic AI systems that consider the emotional aspect of human affect, such as monitoring mental health, dealing with customers, or human-computer interaction.
- *Unspoken Signals* will tackle this issue using an AI driven application that can decode vocal signals and provide an interpretation of just about any emotional type. The project will utilize RAVDESS Emotional Speech Audio dataset and continue to explore how dimensions of emotional expression correlate with various acoustic features - with the hope to build some models that will be able to discover not just the emotional expression, but also the acoustic representations of emotions through voiced and vocalized language. It is not only about establishing classification categories for emotions like happiness, sadness, anger, fear, etc, but making the implicit meaning of how acoustic features can translate to emotional meaning, therefore getting machines one step further to developing some form of intuitive emotional intelligence.

- **Goal of the Project:**

- *Unspoken Signals* is a project to teach machines to learn the emotional richness, expressed through speech, in the way we interpret, without thought of joy, sadness, anger, and a kingdom of others in another person's tone. While many speech/emotion systems

simply classify furthermore understand emotion in speech, we aim to analyze the voice to find the elements of the voice, such as pitch, pace, energy, and rhythm, to understand the emotional pattern. We want to look beyond the classification of emotion and towards why the specific characteristics of the voice create specific emotional responses.

- ***Unspoken Signals*** will create a flow between sound and sentiment, in the way that we flow as humans to interpret facial signals to vocal signals everyday. This initiative aims to bring machines to an intuition of the richness or depths of emotion’s impact to comprehend the intangibility of emotion from sound, vocals alone.

3 Dataset Details

- **Name of the Dataset:** RAVDESS Emotional Speech Audio
- **Description of the dataset:** Speech audio-only files (16bit, 48kHz .wav) from the RAVDESS.
 - Full dataset of speech and song, audio and video (24.8 GB) available from Zenodo. Construction and perceptual validation of the RAVDESS is described in our Open Access paper in PLoS ONE.
 - Zenodo Reference: <https://zenodo.org/records/1188976>
 - PLoS ONE Reference: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0196391>
- **Dataset Files:** This portion of the RAVDESS contains 1012 files: 44 trials per actor x 23 actors = 1012. The RAVDESS contains 24 professional actors (12 female, 12 male), vocalizing two lexically-matched statements in a neutral North American accent. Song emotions includes calm, happy, sad, angry, and fearful expressions. Each expression is produced at two levels of emotional intensity (normal, strong), with an additional neutral expression.
- **File naming conventions:** Each of the 1012 files has a unique filename. The filename consists of a 7-part numerical identifier (e.g., 03-02-06-01-02-01-12.wav). These identifiers define the stimulus characteristics:
- **Filename identifiers:**
 - Modality (01 = full-AV, 02 = video-only, 03 = audio-only).
 - Vocal channel (01 = speech, 02 = song).
 - Emotion (01 = neutral, 02 = calm, 03 = happy, 04 = sad, 05 = angry, 06 = fearful, 07 = disgust, 08 = surprised).
 - Emotional intensity (01 = normal, 02 = strong). NOTE: There is no strong intensity for the ‘neutral’ emotion.
 - Statement (01 = “Kids are talking by the door”, 02 = “Dogs are sitting by the door”).
 - Repetition (01 = 1st repetition, 02 = 2nd repetition).
 - Actor (01 to 24. Odd numbered actors are male, even numbered actors are female).
- **Filename example:** 03-02-06-01-02-01-12.wav
 - Audio-only (03)
 - Song (02)
 - Fearful (06)
 - Normal intensity (01)

- Statement “dogs” (02)
- 1st Repetition (01)
- 12th Actor (12)
- Female, as the actor ID number is even.

4 Mount Google Drive

```
[2]: from google.colab import drive
drive.mount('/content/drive')
```

Mounted at /content/drive

5 Extract Audio Dataset

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[ ]: !unzip '/content/drive/MyDrive/MS_in_AAI/Courses_and_Projects/
    ↵AAI-510-IN2_Machine learning - Fundamentals and Applications/
    ↵AAI-510-IN2_Final Project/AAI-510-IN2_Dataset/
    ↵RAVDESS_EmotionaSpeech_Audio_Dataset.zip' -d '/content/
    ↵extracted_speech_audio_dataset'
```

Archive:

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Project/AAI-510-IN2_Dataset/RAVDESS_EmotionaSpeech_Audio_Dataset.zip
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/content/extracted_speech_audio_dataset/Actor_24/03-01-06-01-01-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-06-01-01-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-06-01-02-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-06-01-02-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-06-02-01-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-06-02-01-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-06-02-02-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-06-02-02-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-07-01-01-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-07-01-01-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-07-01-02-01-24.wav
    inflating:
```

```
/content/extracted_speech_audio_dataset/Actor_24/03-01-07-01-02-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-07-02-01-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-07-02-01-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-07-02-02-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-07-02-02-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-08-01-01-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-08-01-01-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-08-01-02-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-08-01-02-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-08-02-01-01-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-08-02-01-02-24.wav
    inflating:
/content/extracted_speech_audio_dataset/Actor_24/03-01-08-02-02-01-24.wav
    inflating:
/inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_01/03-01-01-01-01-01.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_01/03-01-01-01-02-01.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_01/03-01-01-02-01-01.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_01/03-01-02-01-01-01.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_01/03-01-02-01-02-01.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_01/03-01-02-02-01-01.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_01/03-01-02-01-01-01.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_01/03-01-02-01-02-01.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_01/03-01-02-02-01-01.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
```



```
24/Actor_24/03-01-07-01-02-02-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-07-02-01-01-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-07-02-01-02-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-07-02-02-01-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-07-02-02-02-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-08-01-01-01-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-08-01-01-02-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-08-01-02-01-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-08-01-02-02-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-08-02-01-01-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-08-02-01-02-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-08-02-02-01-24.wav
    inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-
24/Actor_24/03-01-08-02-02-02-24.wav
```

6 Install and Import all the libraries

```
[ ]: # Install "pyloudnorm" library (the audio's loudness and peak normalization library)
!pip install pyloudnorm
```

```
Collecting pyloudnorm
  Downloading pyloudnorm-0.1.1-py3-none-any.whl.metadata (5.6 kB)
Requirement already satisfied: scipy>=1.0.1 in /usr/local/lib/python3.11/dist-packages (from pyloudnorm) (1.15.3)
Requirement already satisfied: numpy>=1.14.2 in /usr/local/lib/python3.11/dist-packages (from pyloudnorm) (2.0.2)
Requirement already satisfied: future>=0.16.0 in /usr/local/lib/python3.11/dist-packages (from pyloudnorm) (1.0.0)
  Downloading pyloudnorm-0.1.1-py3-none-any.whl (9.6 kB)
Installing collected packages: pyloudnorm
  Successfully installed pyloudnorm-0.1.1
```

```
[ ]: !pip install xgboost
```

```
Requirement already satisfied: xgboost in /usr/local/lib/python3.11/dist-
```

```
packages (2.1.4)
Requirement already satisfied: numpy in /usr/local/lib/python3.11/dist-packages
(from xgboost) (2.0.2)
Requirement already satisfied: nvidia-nccl-cu12 in
/usr/local/lib/python3.11/dist-packages (from xgboost) (2.21.5)
Requirement already satisfied: scipy in /usr/local/lib/python3.11/dist-packages
(from xgboost) (1.15.3)
```

```
[ ]: import os
import gc
import math
import itertools
import json
import time
import librosa
import numpy as np
import pandas as pd
import seaborn as sns
from tqdm import tqdm
import pyloudnorm as pyln
import IPython.display as ipd
import matplotlib.pyplot as plt
import matplotlib.cm as cm
from joblib import delayed, Parallel

import warnings
warnings.filterwarnings("ignore")

%matplotlib inline

import torch
import torch.nn as nn
import torch.nn.functional as F
from torch.utils.data import Dataset, DataLoader

import torchaudio
import torchaudio.transforms as T

from sklearn.preprocessing import LabelEncoder, StandardScaler, label_binarize
from sklearn.ensemble import RandomForestClassifier, ExtraTreesClassifier, ▾
    ↳ GradientBoostingClassifier, AdaBoostClassifier, BaggingClassifier
from sklearn.linear_model import LogisticRegression
from sklearn.svm import SVC
from sklearn.model_selection import train_test_split
from sklearn.metrics import accuracy_score, precision_score, recall_score, ▾
    ↳ f1_score, confusion_matrix, roc_curve, auc, roc_auc_score
from xgboost import XGBClassifier
```

```

from sklearn.neighbors import KNeighborsClassifier
from sklearn.neural_network import MLPClassifier
from sklearn.naive_bayes import GaussianNB
from sklearn.discriminant_analysis import QuadraticDiscriminantAnalysis
from lightgbm import LGBMClassifier
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Dropout
from tensorflow.keras.utils import to_categorical
from sklearn.preprocessing import StandardScaler
from tensorflow.keras.layers import Activation, BatchNormalization

```

7 EDA and Audio Data Preprocessing

7.0.1 1. Set Base Directory

- We will set the root directory, which is the dataset (which contains the .wav files) extracted in this location.
-

7.0.2 2. Create Lists

- `file_emotion`: saves numeric emotion codes extracted from the file naming.
 - `file_path`: saves full file paths of the .wav files
-

7.0.3 3. Create File Traversal Function

- We will create a helper function called `capture_audio_file_paths()` to traverse the directory.
 - For each .wav file when traversing:
 - It will extract the metadata (emotion code) from the name of the file.
 - It will save the emotion code and full path to respective lists.
 - It will just skip any malformed filenames.
-

7.0.4 4. Capture Files from Dataset Folders

- We will call the helper function on:
 - A subdirectory with all of the actor folders.
 - The base directory itself (ceasing it has .wav files directly under it).
-

7.0.5 5. Create and Combine into a DataFrame

- We will convert those lists (`file_emotion` and `file_path`) to Pandas DataFrames. Then, we will concatenate them into a table (`data`) a column for:

- Emotions
 - Path.
-

7.0.6 6. Map Numeric Emotion Codes to Labels

- We will use a dictionary (`emotion_map`) to map: | Emotion Code | Emotion Label | | ——————|—————| | 1 | neutral | | 2 | calm | | 3 | happy | | 4 | sad | | 5 | angry | | 6 | fear | | 7 | disgust | | 8 | surprise |
 - Then update the emotion column with the values from the dictionary above.
-

7.0.7 7. Save to CSV

- We will create a new directory called `EmotionData`.
 - We will save the DataFrame object to `emotion_audio_dataset.csv` and it allows us to get back to later.
-

7.0.8 8. Plot Emotion Distribution

- We will set the Seaborn style/theme.
- We will plot a count bar chart of how many samples there are of each emotion.
- We will save it as `emotions_plot.png`.

7.0.9 10. Spectrogram Batch Processing

- Create `process_in_batches()`:
 - Break the dataset into chunks (or batches).
 - Create spectrograms for all the chunks/batches.
 - Use garbage collection to manage memory.

7.0.10 12. Audio Features

- For each file in the sample:
- **Duration:** Total time in seconds.
- **Pitch:** Mean pitch value with pitch tracking.
- **Energy:** Mean signal energy (volume).
- **ZCR (Zero-Crossing Rate):** Rate of change of the amplitude.

Put all the values into lists and add to the sampleDataFrame.

Let us understand the basic meaning of each Audio feature here:

Feature	Description	Purpose in Emotion Analysis
Duration	The entirety of the audio recording length in seconds.	Some emotions (like <i>calm</i> or <i>sad</i>) may emerge when expressed in longer or slower speech.

Feature	Description	Purpose in Emotion Analysis
Pitch	Perceived audio signal frequency, often in Hertz (Hz).	High frequency may show an emotion like <i>surprise or happy</i> and lower frequency signals of <i>sadness</i> .
Energy	Average signal power over time (mean of these squared amplitude values).	High energy is typical for example with <i>angry or happy</i> speech. Low or medium energy is likely for example with <i>sad or neutral</i> speech.
ZCR (Zero Crossing Rate)	The number of times the audio signal changes sign (crosses the zero line) over time.	Higher zero crossing rate might represent noise yet also excited speech (like <i>surprise, or angry</i>). Overall lower rates reflect less noise and calm or monotone speech.
Spectrogram	Visual representation of the frequency content of the audio signal of the recording over time. A color intensity representing amplitude.	Spectrograms provide the input that allow deep learning models (i.e. CNNs) to learn patterns around the vocal frequency content representative of emotion.
MFCC (Mel Frequency Cepstral Coefficients)	A compact representation of the short-term power spectrum of a sound, modelled on human hearing (mel scale).	Captures <i>timbre</i> and <i>tone</i> variations in speech; commonly used for speech and emotion recognition in ML models.

7.0.11 13. Visualize Audio Feature as Emotion

- Build the following visualization:
- **Boxplot:** Duration
- **Violin Plot:** Pitch, energy
- **Boxplot:** ZCR
- Use respective color palettes per emotion.

7.0.12 16. Combine All the Features

- Create a DataFrame from the MFCC feature list.
- Merge it with the original sample's (Pitch, Energy, ZCR, Duration, and Emotions).
- Final output: A complete feature set ready to use for machine learning.

```
[ ]: # Base directory where files are extracted
base_dir = "/content/extracted_speech_audio_dataset"
```

```
[ ]: file_emotion = []
file_path = []

# Helper function to process all .wav files in a given directory tree
```

```

def capture_audio_file_paths(file_base_path):
    for root, dirs, files in os.walk(file_base_path):
        for file in files:
            if file.endswith('.wav'):
                parts = file.split('.')[0].split('-')
                if len(parts) >= 3:
                    try:
                        emotion_code = int(parts[2])
                        file_emotion.append(emotion_code)
                        file_path.append(os.path.join(root, file))
                    except ValueError:
                        continue # skip non-standard filenames

```

```

[ ]: # Parse both locations
capture_audio_file_paths(os.path.join(base_dir, "audio_speech_actors_01-24"))
capture_audio_file_paths(base_dir) # this includes Actor_01 to Actor_24
    ↪directly under /content/extracted_speech_audio_dataset

# Create a dataframe
emotion = pd.DataFrame(file_emotion, columns=['Emotions'])
path = pd.DataFrame(file_path, columns=['Path'])
data = pd.concat([emotion, path], axis=1)

# Emotion label mapping
emotion_map = {
    1: 'neutral',
    2: 'calm',
    3: 'happy',
    4: 'sad',
    5: 'angry',
    6: 'fear',
    7: 'disgust',
    8: 'surprise'
}

data['Emotions'] = data['Emotions'].map(emotion_map)

```

```

[ ]: # Save to CSV
emotion_data = "/content/EmotionData"
os.makedirs(emotion_data, exist_ok=True)
data.to_csv(os.path.join(emotion_data, "emotion_audio_dataset.csv"), ↪
    index=False)

```

```

[ ]: # View the CSV
data.head(25)

```

```
[ ]: Emotions Path
0      sad /content/extracted_speech_audio_dataset/audio_...
1    angry /content/extracted_speech_audio_dataset/audio_...
2      sad /content/extracted_speech_audio_dataset/audio_...
3      sad /content/extracted_speech_audio_dataset/audio_...
4    happy /content/extracted_speech_audio_dataset/audio_...
5  disgust /content/extracted_speech_audio_dataset/audio_...
6     calm /content/extracted_speech_audio_dataset/audio_...
7    happy /content/extracted_speech_audio_dataset/audio_...
8    happy /content/extracted_speech_audio_dataset/audio_...
9    happy /content/extracted_speech_audio_dataset/audio_...
10   calm /content/extracted_speech_audio_dataset/audio_...
11   fear /content/extracted_speech_audio_dataset/audio_...
12  disgust /content/extracted_speech_audio_dataset/audio_...
13     sad /content/extracted_speech_audio_dataset/audio_...
14   angry /content/extracted_speech_audio_dataset/audio_...
15    fear /content/extracted_speech_audio_dataset/audio_...
16    fear /content/extracted_speech_audio_dataset/audio_...
17   angry /content/extracted_speech_audio_dataset/audio_...
18   angry /content/extracted_speech_audio_dataset/audio_...
19     calm /content/extracted_speech_audio_dataset/audio_...
20  disgust /content/extracted_speech_audio_dataset/audio_...
21  disgust /content/extracted_speech_audio_dataset/audio_...
22 surprise /content/extracted_speech_audio_dataset/audio_...
23 neutral /content/extracted_speech_audio_dataset/audio_...
24    happy /content/extracted_speech_audio_dataset/audio_...
```

```
[ ]: # Set the Seaborn theme
sns.set_theme(
    context='notebook',
    style='darkgrid',
    palette='mako',
    font='sans-serif',
    font_scale=1,
    color_codes=True
)

# Create a figure
plt.figure(figsize=(14, 8))

# Plot the count of each emotion
sns.countplot(
    x='Emotions',
    data=data,
    order=data['Emotions'].value_counts().index,
    palette='pastel'
)
```

```

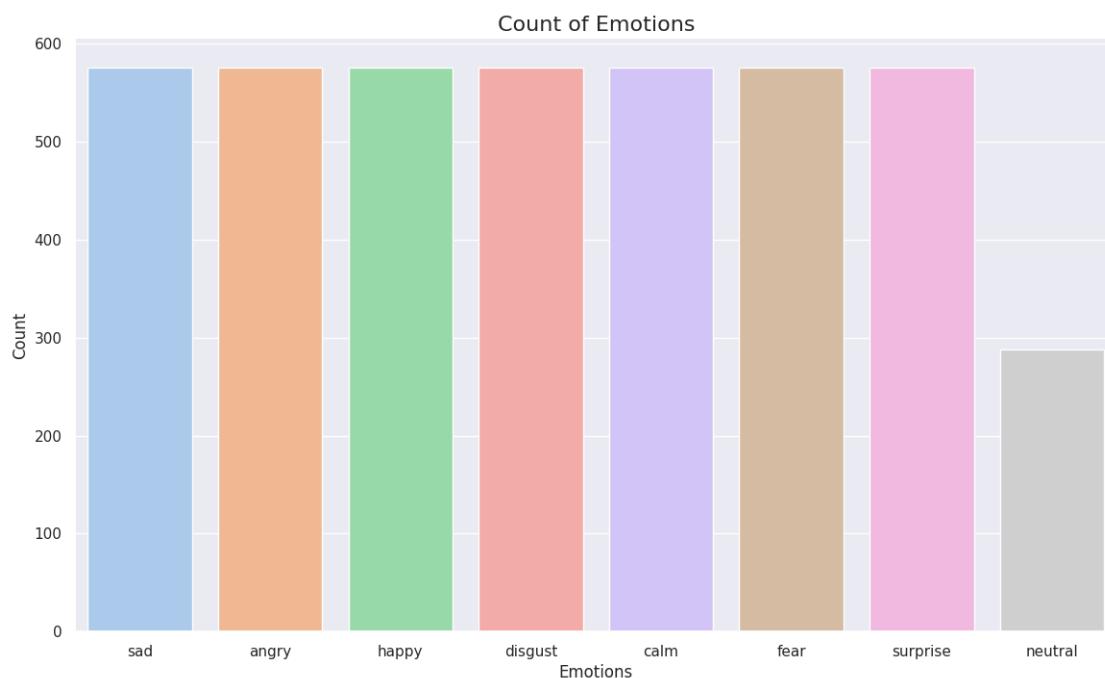
# Set plot labels and title
plt.title('Count of Emotions', fontsize=16)
plt.ylabel('Count', fontsize=12)
plt.xlabel('Emotions', fontsize=12)

# Remove top and right spines
sns.despine(top=True, right=True)

# Save the plot to the same EmotionData directory
plt.savefig(os.path.join(emotion_data, "emotions_plot.png"))

# Show the plot
plt.show()

```



```

[ ]: def create_and_save_spectrogram(file_path, emotion_label, save_root):
    try:
        y, sr = librosa.load(file_path, duration=5.0)
        X = librosa.stft(y)
        Xdb = librosa.amplitude_to_db(abs(X))

        emotion_dir = os.path.join(save_root, emotion_label)
        os.makedirs(emotion_dir, exist_ok=True)

        base_name = os.path.basename(file_path).replace('.wav', '.png')

```

```

    save_path = os.path.join(emotion_dir, base_name)

    plt.figure(figsize=(10, 3))
    librosa.display.specshow(Xdb, sr=sr, x_axis='time', y_axis='hz')
    plt.colorbar(format="%+2.0f dB")
    plt.title(f"emotion_label]", fontsize=10)
    plt.tight_layout()
    plt.savefig(save_path)
    plt.close()

except Exception as e:
    print(f"Failed creating spectrogram for {file_path}: {e}")

```

```

[ ]: def process_in_batches(data, batch_size=100):
    total = len(data)
    for start in range(0, total, batch_size):
        end = min(start + batch_size, total)
        batch = data.iloc[start:end]
        print(f"Processing batch: {start}-{end}")
        for idx, row in tqdm(batch.iterrows(), total=len(batch), desc=f"Batch_{start//batch_size + 1}"):
            create_and_save_spectrogram(row['Path'], row['Emotions'], spectrogram_root)
    gc.collect()

```

```

[ ]: # Directory to save spectrograms
spectrogram_root = os.path.join(emotion_data, "spectrograms")

# Call the function to process
process_in_batches(data, batch_size=100)

```

Processing batch: 0-100
 Batch 1: 100% | 100/100 [01:05<00:00, 1.52it/s]

Processing batch: 100-200
 Batch 2: 100% | 100/100 [00:51<00:00, 1.94it/s]

Processing batch: 200-300
 Batch 3: 100% | 100/100 [00:50<00:00, 2.00it/s]

Processing batch: 300-400
 Batch 4: 100% | 100/100 [00:47<00:00, 2.11it/s]

Processing batch: 400-500
 Batch 5: 100% | 100/100 [00:48<00:00, 2.04it/s]

Processing batch: 500-600

```

Batch 6: 100%| 100/100 [00:45<00:00, 2.18it/s]
Processing batch: 600-700
Batch 7: 100%| 100/100 [00:48<00:00, 2.06it/s]
Processing batch: 700-800
Batch 8: 100%| 100/100 [00:48<00:00, 2.08it/s]
Processing batch: 800-900
Batch 9: 100%| 100/100 [00:46<00:00, 2.13it/s]
Processing batch: 900-1000
Batch 10: 100%| 100/100 [00:47<00:00, 2.12it/s]
Processing batch: 1000-1100
Batch 11: 37%| 37/100 [00:18<00:26, 2.37it/s]

```

```

[ ]: # Take a random sample (e.g., 250 files)
sample_audio_data = data.sample(n=1500, random_state=42).copy()

# Initialize lists
audio_durations = []
audio_pitches = []
audio_energies = []
audio_zcr = []

for path in sample_audio_data['Path']:
    y, sr = librosa.load(path, sr=None)
    pitches_, magnitudes = librosa.piptrack(y=y, sr=sr)
    pitch = pitches_[magnitudes > np.median(magnitudes)].mean()
    energy = np.mean(y**2)
    duration = librosa.get_duration(y=y, sr=sr)
    zcr = np.mean(librosa.feature.zero_crossing_rate(y=y))

    audio_pitches.append(pitch)
    audio_energies.append(energy)
    audio_durations.append(duration)
    audio_zcr.append(zcr)

# Add columns to DataFrame
sample_audio_data['Duration'] = audio_durations
sample_audio_data['Pitch'] = audio_pitches
sample_audio_data['Energy'] = audio_energies
sample_audio_data['ZCR'] = audio_zcr

```

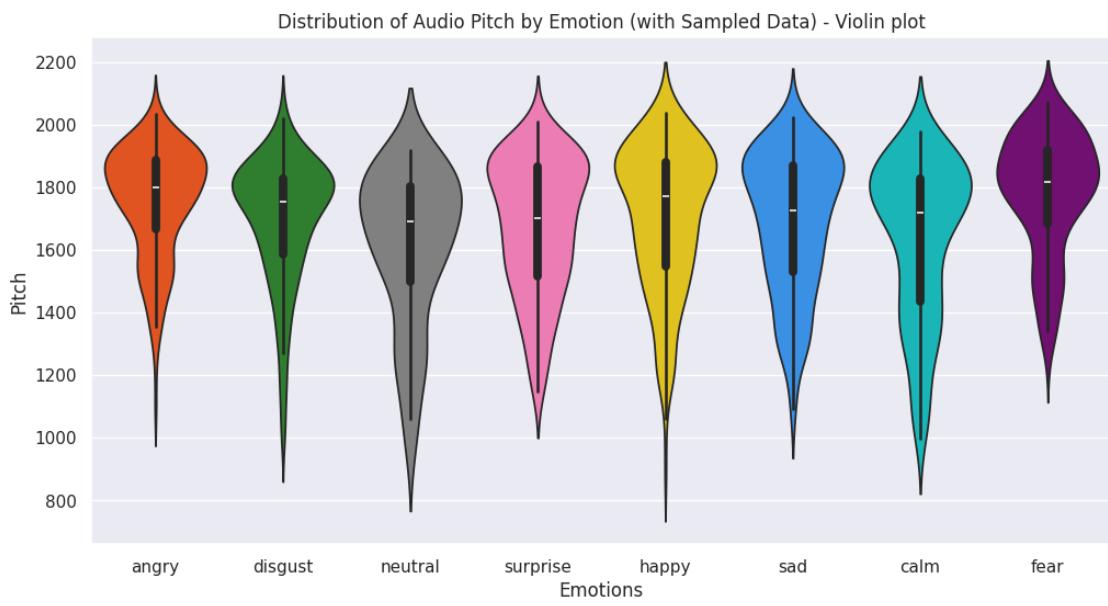
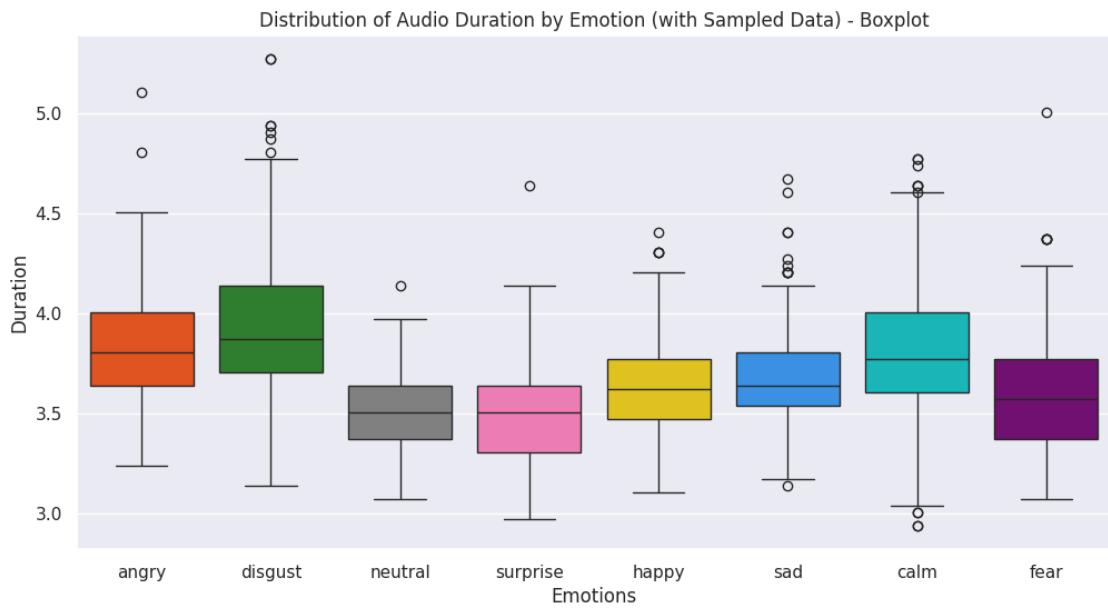
```
[ ]: custom_palette = {
    "happy": "#FFD700",      # gold
    "sad": "#1E90FF",       # dodger blue
    "angry": "#FF4500",      # orange red
    "neutral": "#808080",    # gray
    "calm": "#00CED1",       # dark turquoise
    "fear": "#800080",       # purple
    "disgust": "#228B22",     # forest green
    "surprise": "#FF69B4"     # hot pink
}

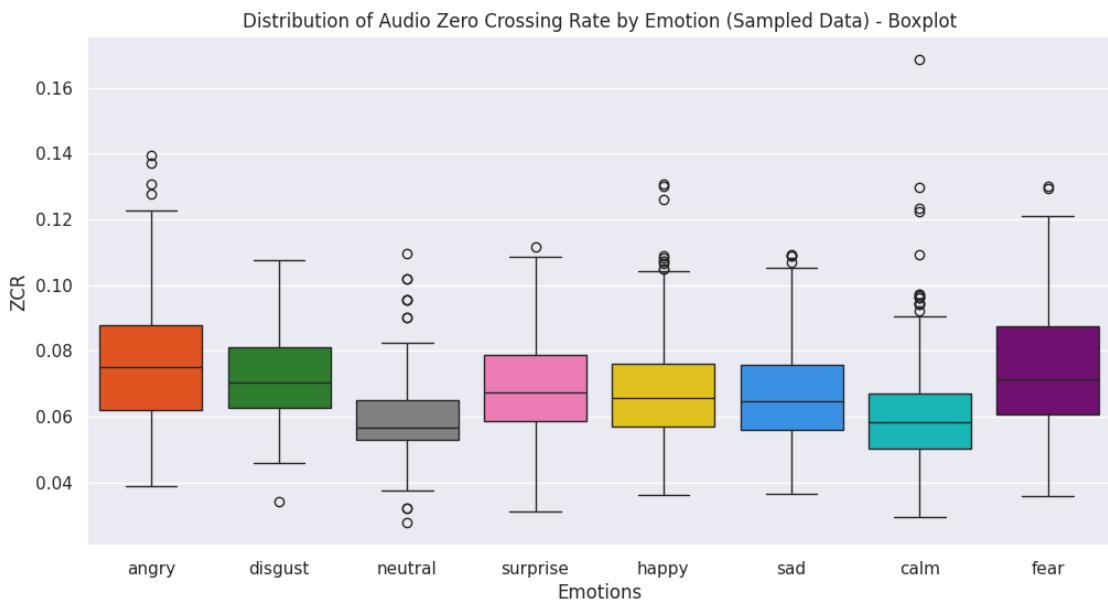
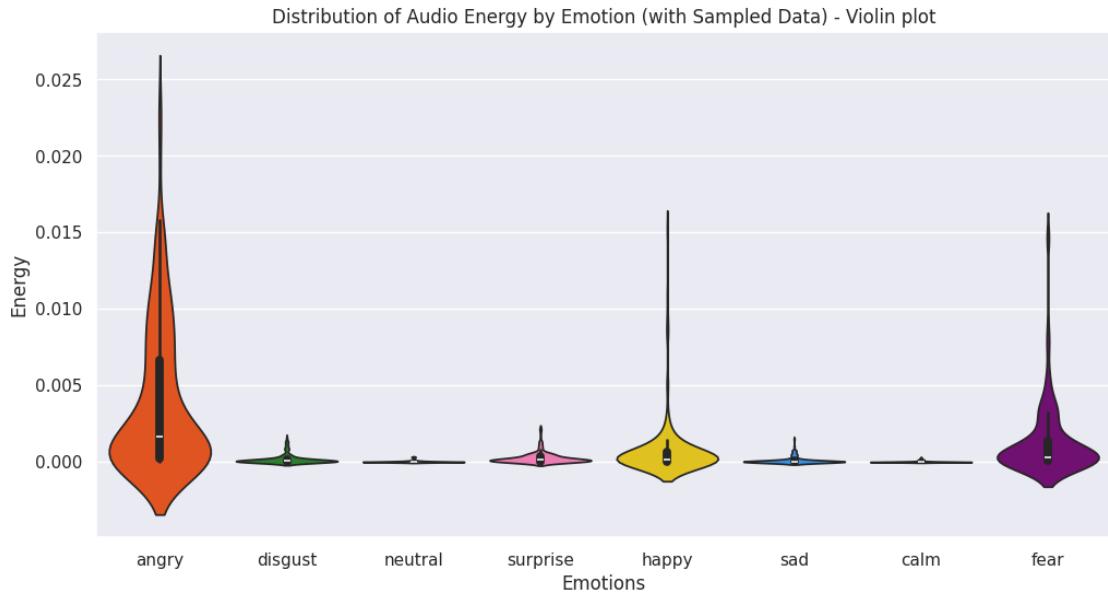
# Duration - Boxplot with custom colors
plt.figure(figsize=(12, 6))
sns.boxplot(x='Emotions', y='Duration', data=sample_audio_data, ▾
            palette=custom_palette)
plt.title("Distribution of Audio Duration by Emotion (with Sampled Data) - ▾
           Boxplot")
plt.show()
print("\n\n")

# Pitch - Violin plot
plt.figure(figsize=(12, 6))
sns.violinplot(x='Emotions', y='Pitch', data=sample_audio_data, ▾
                palette=custom_palette)
plt.title("Distribution of Audio Pitch by Emotion (with Sampled Data) - Violin ▾
           plot")
plt.show()
print("\n\n")

# Energy - Violin plot
plt.figure(figsize=(12, 6))
sns.violinplot(x='Emotions', y='Energy', data=sample_audio_data, ▾
                palette=custom_palette)
plt.title("Distribution of Audio Energy by Emotion (with Sampled Data) - Violin ▾
           plot")
plt.show()

# ZCR - Boxplot
plt.figure(figsize=(12, 6))
sns.boxplot(x='Emotions', y='ZCR', data=sample_audio_data, ▾
            palette=custom_palette)
plt.title("Distribution of Audio Zero Crossing Rate by Emotion (Sampled Data) - ▾
           Boxplot")
plt.show()
```





```
[ ]: # Ensure each emotion is a string (fix nested arrays or wrong types)
def clean_emotion(value):
    # If it's a numpy array or list like ['happy'], take the first element
    if isinstance(value, (np.ndarray, list)):
        return str(value[0])
    return str(value)
```

```
[ ]: # Apply the cleaning function
sample_audio_data['Emotions'] = sample_audio_data['Emotions'].
    ↪apply(clean_emotion)

[ ]: sample_audio_data['Emotions'].apply(type).unique()

[ ]: array([<class 'str'>], dtype=object)

[ ]: sample_audio_data['Emotions'].unique()

[ ]: array(['angry', 'disgust', 'neutral', 'surprise', 'happy', 'sad', 'calm',
       'fear'], dtype=object)

[ ]: # Extract MFCCs (e.g., 13 coefficients) and average over time axis
def extract_mfcc(file_path, n_mfcc=13):
    try:
        y, sr = librosa.load(file_path, sr=None)
        mfccs = librosa.feature.mfcc(y=y, sr=sr, n_mfcc=n_mfcc)
        mfccs_mean = np.mean(mfccs, axis=1) # Take mean over time
        return mfccs_mean
    except Exception as e:
        print(f"Error extracting MFCCs from {file_path}: {e}")
    return np.zeros(n_mfcc)

[ ]: # Extract MFCCs for all files and stack them
mfcc_features = []

for path in sample_audio_data['Path']:
    mfcc = extract_mfcc(path)
    mfcc_features.append(mfcc)

# Convert to DataFrame with reset index to align with sample_audio_data
mfcc_df = pd.DataFrame(mfcc_features, columns=[f'MFCC_{i+1}' for i in
    ↪range(13)])
mfcc_df.reset_index(drop=True, inplace=True)
sample_audio_data.reset_index(drop=True, inplace=True)

[ ]: # Concatenate all indices are aligned (0-249)
features = pd.concat([
    mfcc_df,
    sample_audio_data[['Pitch', 'Energy', 'ZCR', 'Duration', 'Emotions']]
], axis=1)

[ ]: features.head(50)

[ ]:          MFCC_1      MFCC_2      MFCC_3      MFCC_4      MFCC_5      MFCC_6  \
0   -530.949768  56.710712 -17.588903   3.702265  -7.364575  -5.028224
```

1	-688.991760	52.997437	-0.694921	10.821215	-1.606246	12.015389
2	-707.477356	64.675331	1.403847	12.914077	-5.154926	14.195786
3	-577.529358	66.424767	-12.177218	-3.254843	-3.844868	-1.337051
4	-520.566650	57.123196	-0.477673	6.285970	-3.306065	4.898886
5	-576.726746	75.477386	-17.455122	2.709566	5.712685	7.649990
6	-758.854370	71.904793	19.165863	27.339312	8.181487	17.790678
7	-632.525146	85.255318	0.547400	7.576108	9.906102	17.834745
8	-750.391052	80.876678	14.441536	15.772464	5.003344	15.426698
9	-675.851807	68.959435	-4.962603	5.423141	0.609842	3.160732
10	-738.571411	98.130775	7.363718	12.641451	4.109509	17.988504
11	-558.051208	64.939476	-6.308864	11.722996	3.860692	7.621563
12	-648.552490	72.062843	-7.534307	7.673362	-3.249207	2.910233
13	-595.356445	62.380440	-4.747577	6.534198	-6.355627	2.757230
14	-738.059387	82.475418	17.920816	19.800371	11.051210	16.203539
15	-702.187622	53.138821	4.244968	18.424067	-1.137204	5.611201
16	-689.394043	70.910362	1.613997	13.872520	3.828407	11.299436
17	-627.873596	63.898327	-3.407576	-0.134103	-7.709570	6.313606
18	-596.475098	77.723396	-1.686720	11.058089	12.932031	19.027950
19	-673.703796	75.747032	14.209861	21.928139	9.814887	20.580538
20	-742.292603	63.671303	-1.489987	17.553986	0.073392	8.155811
21	-490.474670	64.447304	-8.425392	7.454643	2.263212	12.092965
22	-546.742798	65.570770	0.508001	11.213584	1.876471	9.438198
23	-719.277344	59.596893	5.283475	14.971994	-4.221050	11.400226
24	-638.723633	66.814674	5.833015	16.455235	3.771787	11.230489
25	-708.077942	50.660461	-0.220717	13.301193	-8.692360	8.440870
26	-572.094238	50.042564	-21.697390	4.183290	-5.042517	-0.831468
27	-621.984863	74.449593	-7.038409	8.357906	-1.749748	3.807959
28	-621.866089	65.245857	-11.991793	7.411134	-0.519485	7.619534
29	-557.591370	79.300873	-10.559692	17.806805	-2.841906	10.685294
30	-736.272339	67.015282	0.444734	12.498981	-10.081483	3.144838
31	-660.805298	71.031380	-4.319817	9.917310	-1.543240	9.513564
32	-401.387054	51.261532	-13.474899	-2.606121	-9.515670	3.831839
33	-711.252014	65.044197	-3.045924	13.515722	-1.686568	5.794518
34	-387.105774	57.350224	-14.919951	-1.104706	-0.763922	-2.600334
35	-491.464264	52.547829	-22.691208	4.356894	-9.370849	-4.891275
36	-371.465759	70.171585	-23.333237	11.865147	-2.593794	-0.462333
37	-602.720886	62.845188	-8.394002	6.589411	-4.375909	1.435626
38	-455.846466	39.403099	-21.992670	-2.562673	-8.548673	0.117092
39	-606.977661	73.963478	6.360736	27.191916	3.858940	16.837133
40	-557.014343	56.569588	-11.098543	6.483811	-4.321877	10.319003
41	-603.420837	63.460587	-2.512318	13.960493	-5.738648	10.271082
42	-557.113892	61.539768	-1.374165	12.489706	2.005976	8.978362
43	-590.405701	71.679207	2.785215	11.256137	3.145608	10.231235
44	-772.605225	74.988365	-2.319596	10.768793	-5.314707	10.790870
45	-722.562866	66.428993	1.084406	14.247135	-4.504014	3.756030
46	-595.980408	52.181553	-5.219048	5.122527	-2.670915	0.082706
47	-477.796997	31.894796	-23.476091	2.052141	-16.892900	-7.158306

48	-714.357971	72.247696	-3.808667	7.487391	-5.362574	6.926548		
49	-583.700195	58.775700	-6.359497	10.300801	-1.274937	8.558703		
	MFCC_7	MFCC_8	MFCC_9	MFCC_10	MFCC_11	MFCC_12	MFCC_13	\
0	-15.431587	-0.901726	-7.518787	-10.244362	-3.968747	-2.881203	-6.480864	
1	-4.315355	5.734336	-5.958421	-2.699236	-3.442643	-2.551252	1.112543	
2	-6.883193	3.021738	-8.002178	-9.591667	-6.035497	-2.394563	1.385672	
3	-13.868962	0.302685	-7.719314	-12.950570	-8.408251	-2.469211	-0.608439	
4	-10.563694	0.206123	-9.693844	-4.864597	-4.338170	-0.898257	-6.139508	
5	-12.940028	0.795564	-5.998858	-9.920557	0.179678	-2.333980	-7.742837	
6	1.274712	9.492997	3.147951	2.681702	1.254204	1.482249	2.804748	
7	-4.611243	1.280184	-0.373141	0.398082	-3.609107	-0.805854	-0.668669	
8	0.746029	2.757376	-4.042686	-0.618749	0.137116	-0.071327	1.722100	
9	-9.528844	2.647469	-9.230493	-3.492379	-2.775557	-0.858337	-3.252905	
10	-6.096860	1.765387	-6.673279	-2.130968	4.278433	-1.448715	-2.150960	
11	-5.836644	4.296150	-4.843230	-1.659126	-7.207257	-3.603410	4.737973	
12	-6.597658	0.034335	-10.937420	-7.287062	-3.408880	0.597124	-6.967582	
13	-10.835930	-5.057255	-8.777452	-2.069309	-8.732697	-5.291111	3.413724	
14	-6.047359	15.335152	-6.862867	-0.200409	-0.811358	-0.957145	1.678449	
15	-9.737691	2.627494	-13.522017	-1.768813	-2.075833	-5.178660	-1.913599	
16	-6.158171	3.869916	-6.675709	-3.858678	-8.293786	-1.883290	1.659171	
17	-11.146294	-3.716662	-8.318820	-4.928344	-8.778995	-2.282259	0.582084	
18	-4.498774	4.822545	3.211482	1.170474	-0.363516	5.747397	3.853143	
19	2.128836	11.945294	2.277593	-1.355676	0.135766	3.596518	3.598920	
20	-9.610529	4.993159	-4.038064	-11.586679	-0.995614	-4.910472	-4.196704	
21	-7.833488	3.884314	2.202237	-3.385450	-7.722024	1.604138	-0.529424	
22	-8.134423	-1.134353	-0.577148	-7.847348	-5.938314	-1.036955	-3.577331	
23	-8.386884	5.431180	-5.619642	-10.144651	0.218412	-4.874405	-4.161412	
24	-6.324031	7.089318	-10.032094	-7.123924	0.194488	1.522184	-0.509010	
25	-12.917727	-1.403536	-15.367787	-3.527174	-5.391857	-3.564029	-6.868892	
26	-14.074547	-0.050433	-10.486915	-10.856223	-6.290061	-3.359067	-6.941516	
27	-3.604062	-0.770256	-12.946666	-3.047894	-4.996516	-7.210418	-1.404394	
28	-13.272074	-0.297851	-10.450953	-12.336401	-5.172411	-3.245183	-8.796328	
29	-6.488108	-3.942619	-13.416121	-7.913074	-4.188865	-8.591356	-2.928657	
30	-11.505702	-3.924440	-10.188942	-6.027127	-9.673841	-7.299730	-5.714432	
31	-10.299267	2.767070	-10.620562	-11.835576	-5.518937	-3.185755	-8.290751	
32	-11.841293	3.278619	-1.299747	-3.883444	-4.124894	0.107253	-3.630729	
33	-1.425392	-0.657199	-5.257640	-3.951848	-2.263127	-4.269534	1.513517	
34	-15.092123	-2.079107	-9.921630	-10.112857	-3.520787	-4.578815	-5.304521	
35	-17.746723	-1.416803	-7.176250	-10.480401	-5.035942	-2.502449	-7.611970	
36	-8.774020	4.477863	-12.264639	-8.386244	-2.069359	-5.866337	-6.640087	
37	-10.295985	3.848105	-10.856516	-5.512211	-4.194157	-1.542342	-4.706222	
38	-9.358397	-3.905083	-5.655101	-7.972375	-8.638764	-1.179207	-6.162721	
39	-4.192284	10.653203	-0.545139	1.308130	-3.622446	1.286399	5.445767	
40	-7.669708	-4.867458	-8.262742	-5.855659	-6.046725	-4.562987	-1.157162	
41	-2.413992	4.424173	-4.890187	-6.735041	-8.776105	-2.467670	1.515881	
42	-18.886354	8.524689	-16.038456	-11.179732	-3.653991	-3.987450	-2.358493	

43	-12.192984	2.593606	-10.011452	-10.451084	-1.040826	-3.629768	-2.711256
44	-11.333268	-6.382631	-9.749052	-8.521235	-0.813156	-2.364093	-2.601497
45	-9.863364	0.036211	-11.028365	-2.415413	-6.606638	-6.270646	-2.672716
46	-11.780094	-5.116186	-11.766125	-5.777168	-4.309497	-1.623907	-8.249356
47	-16.534233	2.093184	-16.666027	-9.390957	-4.582633	-6.798019	-5.869928
48	-13.889935	-0.511554	-11.692696	-0.797561	-0.957153	-1.928067	-3.437814
49	-7.913509	1.139434	-7.879967	-4.218493	-8.814163	-5.463508	0.468384

	Pitch	Energy	ZCR	Duration	Emotions
0	1799.744019	0.000653	0.069943	4.104104	angry
1	1909.444946	0.000033	0.065898	3.470125	disgust
2	1765.176025	0.000017	0.072739	3.536854	neutral
3	1930.319946	0.000227	0.050803	3.903896	angry
4	1249.880249	0.001069	0.107784	3.503500	surprise
5	1739.744751	0.000223	0.072025	3.937271	happy
6	1262.890869	0.000009	0.052809	3.136479	neutral
7	1382.510498	0.000115	0.064403	3.436771	happy
8	1562.259521	0.000010	0.056115	3.436771	sad
9	1710.909912	0.000042	0.055098	3.636958	neutral
10	1628.104858	0.000006	0.054095	3.737062	calm
11	1679.908325	0.000293	0.053787	3.770437	angry
12	1668.081421	0.000065	0.063167	3.870542	disgust
13	1793.198608	0.000158	0.073821	4.170833	disgust
14	1277.150879	0.000008	0.056696	3.603604	calm
15	1828.197266	0.000017	0.096571	3.536875	sad
16	1875.522949	0.000035	0.044231	3.536875	surprise
17	1769.561523	0.000139	0.070298	3.536875	surprise
18	1498.510376	0.000212	0.047307	3.303292	surprise
19	1080.083374	0.000058	0.048856	3.536875	calm
20	1940.432129	0.000014	0.030211	3.603604	calm
21	1679.955811	0.003015	0.073119	3.636979	angry
22	1693.327026	0.000480	0.063031	3.570229	surprise
23	1908.331787	0.000021	0.040766	3.603604	calm
24	1619.269897	0.000055	0.069066	4.070729	disgust
25	1801.894165	0.000012	0.098792	3.837167	disgust
26	2004.794922	0.000303	0.077980	3.236583	fear
27	1736.187744	0.000105	0.072550	3.203208	surprise
28	1805.289795	0.000093	0.094115	3.503500	happy
29	1744.957275	0.000190	0.075986	3.503500	fear
30	1865.040283	0.000011	0.058122	4.037375	calm
31	1722.800903	0.000050	0.094848	3.570229	sad
32	1871.120483	0.007951	0.064689	3.670333	angry
33	1423.831421	0.000035	0.065413	3.036375	surprise
34	1718.740234	0.007786	0.081251	4.170833	angry
35	1873.679199	0.001697	0.069958	4.371042	angry
36	1837.691284	0.007977	0.092693	4.404396	angry
37	1668.330933	0.000192	0.078324	3.770417	angry

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38 1985.505493 0.002646 0.070149 3.937250    happy
39 1669.027832 0.000081 0.075890 3.803812    disgust
40 1616.370972 0.000635 0.093391 3.503500    surprise
41 1503.634155 0.000161 0.070915 2.969625    surprise
42 1977.444214 0.000264 0.168519 3.636958    calm
43 1696.301758 0.000224 0.094443 3.803792    calm
44 1794.985840 0.000006 0.061525 3.436771    sad
45 1772.149170 0.000014 0.068473 3.837167    sad
46 1806.862305 0.000269 0.072395 3.503500    surprise
47 1894.797974 0.002029 0.106259 3.837167    angry
48 1832.287842 0.000007 0.073698 3.737062    disgust
49 1833.682617 0.000280 0.048410 3.570229    surprise

```

[]: features.tail(50)

	MFCC_1	MFCC_2	MFCC_3	MFCC_4	MFCC_5	MFCC_6	\
1450	-576.252136	83.902351	-5.613060	5.997512	13.148571	17.140965	
1451	-549.608521	59.821621	3.986470	18.777025	-10.736347	5.534567	
1452	-724.652161	55.716625	4.621684	12.570419	-2.390850	2.915290	
1453	-509.605896	45.792137	-6.162908	8.651158	-4.831096	-0.030923	
1454	-712.437927	78.734238	-5.351281	15.561357	-4.329194	11.405571	
1455	-535.360046	66.862297	-6.255217	4.612798	0.132151	3.664799	
1456	-463.947296	55.791977	-4.675094	4.485945	-7.206392	4.994133	
1457	-573.581970	84.512520	-9.768131	10.765003	0.062497	11.318466	
1458	-538.494995	77.059799	-9.714148	8.943498	-0.755134	13.815857	
1459	-382.243317	59.969574	-32.373940	-4.047814	-6.247598	-6.855563	
1460	-494.526581	62.234695	-13.827054	4.022485	-5.873456	5.217363	
1461	-671.645752	76.220512	-5.066648	12.957191	13.695049	11.643517	
1462	-644.527771	64.564865	-4.526694	12.617377	-1.339593	8.432860	
1463	-382.979340	66.608582	-17.706032	1.712626	4.908599	9.020983	
1464	-609.593994	46.783237	-4.530296	3.797407	-7.822949	-3.180745	
1465	-612.745300	72.119171	4.390731	24.674278	8.552752	13.575852	
1466	-618.885193	65.211578	-7.112601	5.369632	-13.805950	6.754710	
1467	-388.884216	62.739193	-15.482233	0.468054	-6.506432	7.696176	
1468	-738.571411	98.130775	7.363718	12.641451	4.109509	17.988504	
1469	-476.860413	55.229221	-5.190891	15.668809	-2.583666	4.870916	
1470	-719.909485	83.208832	-6.937643	10.662495	-6.592058	10.782142	
1471	-712.075562	76.019432	12.366280	21.779139	8.561011	15.253534	
1472	-463.132935	70.867317	-11.192143	7.132051	-11.503160	1.683866	
1473	-713.864136	66.125702	15.227443	21.168427	5.660246	15.869121	
1474	-747.631409	52.891716	-4.180786	11.691941	-3.428203	3.413709	
1475	-677.332214	103.013565	4.941693	6.229761	14.362885	14.914571	
1476	-761.483032	71.773376	14.633630	23.550846	8.441536	18.252174	
1477	-455.846466	39.403099	-21.992670	-2.562673	-8.548673	0.117092	
1478	-515.998291	38.055786	-27.663736	-3.225222	-11.483253	-1.980056	
1479	-579.670715	77.368469	-2.240595	9.634315	6.540262	18.944317	
1480	-538.003662	48.876251	-42.743336	-2.712043	-3.054527	5.146502	

1481	-751.650085	79.051102	14.257444	23.402027	9.972133	14.853502
1482	-689.470398	68.112495	3.999788	11.038074	3.308455	15.108302
1483	-720.622192	61.749256	1.793653	14.882030	-0.654519	8.332651
1484	-512.776855	45.480679	-22.158039	1.993872	-7.982536	0.467016
1485	-605.312439	78.914925	-3.125879	9.583420	7.932466	12.383397
1486	-490.326843	57.023918	-8.252707	13.788845	5.498104	13.871115
1487	-788.923462	78.242737	8.959163	18.795086	13.454979	17.358524
1488	-634.485291	71.039749	-6.566928	7.721408	-0.305422	6.991355
1489	-616.690308	53.155006	-13.383676	3.107239	-4.970709	-2.160687
1490	-611.155457	72.807716	7.525245	27.887705	7.331596	14.004911
1491	-625.723755	51.181450	-12.161855	10.705048	-7.248705	-0.742991
1492	-718.600342	60.429588	-7.504327	8.469443	0.098440	2.273504
1493	-561.696655	66.061844	-0.762608	19.809284	5.959435	8.413821
1494	-540.264404	43.222351	-17.589552	1.167436	-4.497149	-2.322750
1495	-608.056763	79.355980	-42.203171	-10.743568	5.452473	2.825938
1496	-671.147339	83.922676	4.414422	18.822296	1.098816	15.853525
1497	-752.794067	92.826988	13.840122	21.288549	7.730475	12.856149
1498	-749.033630	101.306038	5.393279	22.513130	12.124166	22.545036
1499	-568.579285	72.255913	-0.960325	9.171285	2.568779	11.502727

	MFCC_7	MFCC_8	MFCC_9	MFCC_10	MFCC_11	MFCC_12	\
1450	-4.482802	1.225521	3.898202	0.117233	-4.192489	2.592198	
1451	-5.526395	0.865793	-15.845592	-6.647061	-3.756177	-5.951642	
1452	-10.982980	2.046193	-11.857314	-1.330991	-3.332482	-6.052534	
1453	-12.482430	9.538957	-5.068142	-8.011456	-1.556359	-4.365634	
1454	-7.483521	2.417173	-8.861942	-9.116618	-5.105822	-2.184574	
1455	-16.212788	-2.698153	-13.526981	-13.774392	-4.154656	-0.374064	
1456	-12.510364	-1.909506	-9.404054	-8.369539	-6.246582	-0.948422	
1457	-10.694774	0.814193	-9.129473	-3.415508	-3.706591	-1.593670	
1458	-12.097765	-0.363140	-14.664742	-1.731563	-6.433363	-3.992876	
1459	-16.801371	0.028877	-7.471280	0.282932	-12.097858	-3.319858	
1460	-10.575431	-3.960972	-12.859762	-5.571049	-8.623755	-10.310333	
1461	-6.815738	6.645009	-3.886418	-2.520594	1.878753	-1.744221	
1462	-3.338191	-2.138234	-5.568493	-0.895335	-3.653052	-1.889515	
1463	-13.562610	-7.152243	0.254530	-7.342922	-10.889815	-0.449458	
1464	-16.811096	-0.141613	-20.392073	-8.243180	-4.488346	-6.671552	
1465	-10.706611	-0.079564	0.045442	2.418911	-3.445172	-1.592356	
1466	-9.835039	2.523607	-11.782198	-8.704145	-8.247321	-2.508119	
1467	-13.269676	1.848019	-8.492751	-1.686271	-1.293972	-1.473418	
1468	-6.096860	1.765387	-6.673279	-2.130968	4.278433	-1.448715	
1469	-6.622609	1.381127	-0.228902	0.257896	-3.765286	-4.573009	
1470	-4.370418	3.071617	-7.461265	-8.388379	-5.286333	-0.885486	
1471	-6.755793	12.945807	-7.801950	-2.183830	-0.115249	-2.756708	
1472	-4.482834	-5.572930	-13.715826	-3.734334	-6.702277	-11.326709	
1473	-3.165622	7.953099	-2.759756	-3.684051	-1.386997	2.371895	
1474	-6.434531	0.227582	-7.807840	-7.427310	-3.188294	-6.881716	
1475	-5.632416	0.364172	-0.448607	-3.207986	-3.375626	-0.920157	

1476	0.082437	11.601342	-4.075377	-4.015073	0.158292	0.432119
1477	-9.358397	-3.905083	-5.655101	-7.972375	-8.638764	-1.179207
1478	-17.871075	-2.427586	-12.107833	-9.330832	-5.251732	-4.981838
1479	-8.394689	5.892410	3.684941	0.789871	-1.308659	1.481615
1480	-22.605495	-3.842747	-3.808207	-14.554675	-2.215971	3.661035
1481	-2.534623	13.012793	-6.046933	0.347853	-0.659921	-0.744938
1482	-6.331330	2.498303	-2.481705	-1.670319	-5.504648	-2.031564
1483	-10.693089	5.308539	-6.543029	-9.690411	-1.853725	-4.521874
1484	-12.175795	-9.717515	-10.736132	-11.358449	-8.710515	-3.715702
1485	-9.771394	3.009899	-2.524233	-6.630434	-6.937341	0.205224
1486	-5.427896	1.035098	-1.145201	-0.761920	-3.354668	2.231419
1487	-2.457196	7.009903	-4.500436	-0.120026	-1.285369	-2.626377
1488	-15.028293	-12.167973	-16.926113	-4.678617	-3.389843	-0.923981
1489	-12.975248	-0.476768	-10.403996	-10.607459	-5.955286	-2.804203
1490	-10.311299	-0.399400	-1.056008	1.332108	-2.788548	-4.436531
1491	-13.633307	0.366291	-20.579227	-7.092347	-3.326124	-6.980555
1492	-9.096851	1.327376	-10.595312	-6.961360	-5.238770	-2.873956
1493	-16.410505	0.616956	1.286905	-1.993956	-6.198728	-2.971222
1494	-14.634726	-1.789489	-10.922587	-10.481071	-5.681403	-3.548899
1495	-22.118572	-11.734230	-10.780480	-14.367832	-5.315158	4.859441
1496	-4.581458	-1.103555	-9.938231	2.678612	-2.264974	-4.625286
1497	1.942482	8.698071	-0.636301	-2.354827	-3.313907	-0.115121
1498	1.623664	-0.358477	-6.050263	-6.767978	-4.116024	-3.505361
1499	-10.653265	-1.438150	-2.171368	-7.579602	-8.189472	-1.418600

	MFCC_13	Pitch	Energy	ZCR	Duration	Emotions
1450	3.043495	1466.662842	0.000318	0.055886	3.470125	happy
1451	-7.945483	1664.497070	0.000365	0.070312	4.037375	disgust
1452	-3.794274	1858.634766	0.000014	0.057949	3.603604	sad
1453	-3.466866	1231.362061	0.001460	0.060673	3.603604	angry
1454	0.858140	1799.334106	0.000008	0.081488	3.770437	calm
1455	-7.143915	1834.920898	0.000871	0.125994	3.336667	happy
1456	-4.934122	1597.821533	0.002174	0.094305	3.503500	surprise
1457	3.000084	1818.496216	0.000086	0.093264	4.037375	disgust
1458	3.888582	1829.094116	0.000121	0.107713	3.770437	disgust
1459	4.961324	1822.439575	0.010844	0.066787	4.804792	angry
1460	-2.360113	1533.325684	0.000998	0.070073	3.103104	fear
1461	0.272029	1502.634277	0.000039	0.057114	3.436750	happy
1462	1.497704	1591.518921	0.000092	0.063714	3.336667	surprise
1463	0.536631	1938.678101	0.010846	0.079829	4.371042	angry
1464	-6.657808	1841.869507	0.000178	0.070133	3.803792	disgust
1465	2.448945	1710.272827	0.000075	0.070615	4.404396	disgust
1466	0.448447	1840.197876	0.000143	0.078837	3.670333	disgust
1467	-0.117926	1581.468140	0.008964	0.068719	3.970646	angry
1468	-2.150960	1628.104858	0.000006	0.054095	3.737062	calm
1469	-0.322284	1421.371826	0.001475	0.052137	3.536875	angry
1470	1.572411	1741.906982	0.000008	0.073620	3.636958	calm

```

1471 0.262950 963.532104 0.000022 0.062374 3.536854 neutral
1472 0.673786 1686.719727 0.001403 0.084787 4.304312 happy
1473 -0.936049 1038.660400 0.000024 0.058251 3.837167 disgust
1474 -4.050827 1872.952148 0.000011 0.038801 3.236583 angry
1475 1.311289 1658.302612 0.000026 0.068806 3.603583 disgust
1476 1.088438 1165.633667 0.000006 0.070508 3.570250 sad
1477 -6.162721 1985.505493 0.002646 0.070149 3.937250 happy
1478 -10.160073 1995.687256 0.001033 0.099643 3.603604 fear
1479 -0.549216 1558.216309 0.000306 0.058626 3.703708 angry
1480 -7.415465 2022.322388 0.000306 0.109305 4.204187 sad
1481 1.261585 1350.066650 0.000007 0.060709 3.403417 calm
1482 0.744056 1746.981567 0.000035 0.050363 4.004000 calm
1483 -2.274745 1918.618164 0.000019 0.038308 3.470125 calm
1484 -7.639883 1858.757202 0.000613 0.080323 3.570229 fear
1485 0.981306 1788.853638 0.000160 0.071533 3.770417 fear
1486 -0.689352 1844.165649 0.001366 0.057933 3.470146 fear
1487 2.355970 1759.016724 0.000002 0.066240 3.470125 disgust
1488 -9.096961 1859.801514 0.000089 0.084566 3.737062 sad
1489 -7.114357 1853.027222 0.000223 0.059146 3.336667 surprise
1490 0.480406 1492.652222 0.000084 0.072423 4.137458 disgust
1491 -1.404141 1940.965332 0.000047 0.086380 3.737062 disgust
1492 -2.855379 1862.102173 0.000018 0.049154 3.303292 neutral
1493 -0.375253 1711.270996 0.000197 0.057238 4.137479 disgust
1494 -8.019908 1897.831421 0.000746 0.083242 3.603604 happy
1495 -10.820103 2023.957153 0.000077 0.082453 3.603604 happy
1496 2.922202 1574.708252 0.000019 0.056155 3.837167 calm
1497 4.027891 1323.824829 0.000014 0.042575 3.370042 neutral
1498 3.034351 1548.266235 0.000003 0.059714 3.937271 sad
1499 -2.152551 1761.668823 0.000349 0.067582 3.503500 surprise

```

```
[ ]: features['Emotions'].value_counts()
```

```

[ ]: Emotions
surprise    222
fear        213
disgust     204
calm        202
happy       196
angry       183
sad         181
neutral     99
Name: count, dtype: int64

```

```
[ ]: features.describe()
```

```

[ ]:          MFCC_1      MFCC_2      MFCC_3      MFCC_4      MFCC_5 \
count  1500.000000  1500.000000  1500.000000  1500.000000  1500.000000

```

mean	-616.536804	66.128914	-4.888444	10.095770	-0.365069
std	101.990547	14.695105	11.796129	8.017003	6.785505
min	-873.242310	18.962200	-51.957912	-17.508692	-22.980276
25%	-691.658661	56.037944	-12.089696	4.930532	-5.077139
50%	-622.574402	66.424767	-4.148453	10.303168	-0.596484
75%	-554.588226	76.231106	3.313171	14.837873	4.842866
max	-333.377960	115.125786	21.558977	36.563427	21.130016
	MFCC_6	MFCC_7	MFCC_8	MFCC_9	MFCC_10
count	1500.000000	1500.000000	1500.000000	1500.000000	1500.000000
mean	8.175130	-8.386565	0.878536	-7.339055	-5.657850
std	7.021306	5.901298	5.186680	4.989207	4.339794
min	-11.918347	-24.635300	-16.975168	-21.486059	-21.439531
25%	3.156758	-12.189293	-2.561358	-10.798154	-8.697954
50%	8.440870	-8.816299	0.690603	-7.880085	-5.620663
75%	13.473371	-4.471182	4.222466	-3.799453	-2.483162
max	27.950075	10.092591	16.080755	6.087853	7.422122
	MFCC_11	MFCC_12	MFCC_13	Pitch	Energy
count	1500.000000	1500.000000	1500.000000	1500.000000	1.500000e+03
mean	-4.037189	-2.025277	-1.686835	1697.015991	8.541192e-04
std	3.796324	3.250771	3.965726	221.995209	2.366530e-03
min	-16.627752	-15.883946	-13.192415	894.840393	4.478879e-07
25%	-6.545850	-4.033344	-4.850937	1554.609497	2.781700e-05
50%	-4.050446	-2.195989	-1.561038	1754.252930	1.038266e-04
75%	-1.529847	0.079123	1.311591	1866.713989	4.012986e-04
max	9.350845	18.046015	13.240598	2072.602539	2.315510e-02
	ZCR	Duration			
count	1500.000000	1500.000000			
mean	0.069084	3.692645			
std	0.017884	0.331494			
min	0.027717	2.936271			
25%	0.057136	3.470146			
50%	0.066514	3.670333			
75%	0.079430	3.870521			
max	0.168519	5.271937			

[]: features.info()

```

<class 'pandas.core.frame.DataFrame'>
RangeIndex: 1500 entries, 0 to 1499
Data columns (total 18 columns):
 #   Column      Non-Null Count  Dtype  
--- 
 0   MFCC_1      1500 non-null   float32 
 1   MFCC_2      1500 non-null   float32 

```

```

2  MFCC_3      1500 non-null    float32
3  MFCC_4      1500 non-null    float32
4  MFCC_5      1500 non-null    float32
5  MFCC_6      1500 non-null    float32
6  MFCC_7      1500 non-null    float32
7  MFCC_8      1500 non-null    float32
8  MFCC_9      1500 non-null    float32
9  MFCC_10     1500 non-null    float32
10 MFCC_11     1500 non-null    float32
11 MFCC_12     1500 non-null    float32
12 MFCC_13     1500 non-null    float32
13 Pitch       1500 non-null    float32
14 Energy      1500 non-null    float32
15 ZCR         1500 non-null    float64
16 Duration    1500 non-null    float64
17 Emotions    1500 non-null    object
dtypes: float32(15), float64(2), object(1)
memory usage: 123.2+ KB

```

7.1 Label Encoding

7.1.1 Purpose

- ML models work with **numerical inputs**, not the strings. So, categorical labels like:
– 'happy', 'sad', 'angry', neutral, calm, fear, disgust, surprise.
...need to be converted into numbers like:
– 0, 1, 2, 3, 4, 5, 6, 7

This process is called **Label Encoding**.

7.1.2 Why do we need Label Encoding?

Reason	Explanation
Machine Compatibility	A large number of ML models require numerical inputs
Efficient Representation	Encodes categories into unique integers in a space-efficient manner.
Consistent Mapping	All emotions will receive a consistent integer code throughout training and evaluation.
Model Interpretability	The labels like <code>Emotion_Label = 3</code> , can be then understood or reported back to 'neutral'.

```
[ ]: # Encode emotion labels as integers
label_encoder = LabelEncoder()
features['Emotion_Label'] = label_encoder.fit_transform(features['Emotions'])

# Optional: check mapping
```

```

emotions_labels_map = dict(zip(label_encoder.classes_, label_encoder.
    ↪transform(label_encoder.classes_)))
emotions_labels_map

```

```
[ ]: {'angry': np.int64(0),
      'calm': np.int64(1),
      'disgust': np.int64(2),
      'fear': np.int64(3),
      'happy': np.int64(4),
      'neutral': np.int64(5),
      'sad': np.int64(6),
      'surprise': np.int64(7)}
```

8 Modelling

9 Common ML Models for Emotion Classification

We used a varied collection of machine learning models to evaluate performance on emotion recognition using audio features.

9.1 List of ML Models used here

Model Name	Type	Notes
Logistic Regression	Linear Model	Good baseline for multi-class classification
Random Forest	Ensemble - Bagging	Resistant to overfitting (more general classifier), can deal with non-linearity
Extra Trees	Ensemble - Randomized Trees	Faster, more randomized than Random Forest

Model Name	Type	Notes
Gradient Boosting	Ensemble - Boosting	Models sequentially and often performs well from the start
XGBoost	Optimized Gradient Boosting	High performance, regularized
SVM (Linear)	Linear Classifier	Performance is good with high-dimensional data
SVM (RBF)	Kernel-based Classifier	Can handle complex non-linear structure
KNN	Lazy Learner	Simple, non-parametric, distance-based
MLP (Neural Net)	Feedforward Neural Network	Learns a complex pattern, but requires tuning
AdaBoost	Ensemble - Boosting	Focuses on the hard-to-classify samples
Bagging	Ensemble - Bagging	Averages predictions in order to decrease variance

Model Name	Type	Notes
Naive Bayes	Probabilistic Classifier	Assumes independence among features
QDA	Probabilistic Classifier	Creates quadratic boundaries
LightGBM	Gradient Boosting (Tree)	Fast estimation, performs well with large datasets

9.2 Training and Evaluation Strategy

For each model: 1. **Train** on training data (`X_train, y_train`) 2. **Predict** on both training and test data 3. **Evaluate** using key metrics: - Accuracy - Loss (1 - Accuracy) - Precision - Recall - F1 Score 4. **Visualize**: - Confusion Matrix - ROC-AUC Curve

Each model's result (both train and test) will be kept in a results array for comparison.

Each model will have **2 entries**: one for the training set, and one for the test set.

9.3 Visualization Summary

Visualization	Purpose
Confusion Matrix	Shows how frequently predictions are correct per class
ROC-AUC Curve	Visualizes the model's discriminative ability

9.4 With vs. Without Feature Scaling

Many models are **sensitive to feature scale** (e.g., SVM, KNN, MLP). We compare models trained:

- **Without Scaling:**
 - Directly use raw features from MFCC, pitch, energy, etc.
 - Split data into `X_train, X_test, y_train, y_test`
 - Results stored as: `results_no_scaling`

- *With StandardScaler:*
 - Standardize features to have 0 mean and unit variance
 - Apply `StandardScaler().fit_transform()` to all features
 - Split scaled data into `X_train_scaled`, `X_test_scaled`
 - Results stored as: `results_scaled`
-

9.5 Model Training Function Overview

```
def train_evaluate_and_plot(X_train, X_test, y_train, y_test, label_suffix=""):
    - Iterates over each model in `dict_of_ml_models`
    - Trains model
    - Predicts on both train and test data
    - Computes evaluation metrics
    - Plots:
        - Confusion Matrix
        - ROC-AUC (if `predict_proba` is available)
    - Returns results as a Pandas DataFrame
```

9.6 Common functions used to train models

```
[ ]: dict_of_ml_models = {
    "Logistic Regression": LogisticRegression(max_iter=1000),
    "Random Forest": RandomForestClassifier(),
    "Extra Trees": ExtraTreesClassifier(),
    "Gradient Boosting": GradientBoostingClassifier(),
    "XGBoost": XGBClassifier(use_label_encoder=False, eval_metric='mlogloss'),
    "SVM (Linear)": SVC(kernel='linear', probability=True),
    "SVM (RBF)": SVC(kernel='rbf', probability=True),
    "KNN": KNeighborsClassifier(),
    "MLP (Neural Net)": MLPClassifier(max_iter=500),
    "AdaBoost": AdaBoostClassifier(),
    "Bagging": BaggingClassifier(),
    "Naive Bayes": GaussianNB(),
    "QDA": QuadraticDiscriminantAnalysis(),
    "LightGBM": LGBMClassifier()
}
```

9.6.1 Function to train models, evaluate and plot the results

```
[ ]: def train_evaluate_and_plot(X_train, X_test, y_train, y_test, label_suffix=""):
    results = []
    color_map = cm.get_cmap('tab10') # 10 distinct colors
    model_index = 0 # for color indexing

    for name, model in dict_of_ml_models.items():
        print(f"\nTraining {name + label_suffix}...")
```

```

model.fit(X_train, y_train)

# Predictions
y_train_pred = model.predict(X_train)
y_test_pred = model.predict(X_test)
y_test_proba = model.predict_proba(X_test) if hasattr(model, □
↪"predict_proba") else None

# Train Metrics
results.append({
    "Model": name + label_suffix,
    "Set": "Train",
    "Accuracy": accuracy_score(y_train, y_train_pred),
    "Loss": 1 - accuracy_score(y_train, y_train_pred),
    "Precision": precision_score(y_train, y_train_pred, □
↪average='weighted', zero_division=0),
    "Recall": recall_score(y_train, y_train_pred, average='weighted'),
    "F1 Score": f1_score(y_train, y_train_pred, average='weighted')
})

# Test Metrics
results.append({
    "Model": name + label_suffix,
    "Set": "Test",
    "Accuracy": accuracy_score(y_test, y_test_pred),
    "Loss": 1 - accuracy_score(y_test, y_test_pred),
    "Precision": precision_score(y_test, y_test_pred, □
↪average='weighted', zero_division=0),
    "Recall": recall_score(y_test, y_test_pred, average='weighted'),
    "F1 Score": f1_score(y_test, y_test_pred, average='weighted')
})

# Plot side-by-side
fig, axes = plt.subplots(1, 2, figsize=(14, 5))

# Confusion Matrix
cmatrix = confusion_matrix(y_test, y_test_pred)
sns.heatmap(cmatrix, annot=True, fmt="d", cmap="Blues",
            xticklabels=class_names, yticklabels=class_names,
            ax=axes[0], cbar=False, annot_kws={"size": 10})
axes[0].set_title(f'Confusion Matrix\n{name + label_suffix}', □
↪fontsize=12)
axes[0].set_xlabel("Predicted")
axes[0].set_ylabel("Actual")
axes[0].tick_params(axis='x', rotation=45)
axes[0].tick_params(axis='y', rotation=0)

```

```

# ROC-AUC
if y_test_proba is not None:
    y_test_bin = label_binarize(y_test, classes=np.unique(y))
    if y_test_proba.shape[1] == n_classes:
        fpr, tpr, roc_auc = {}, {}, {}
        for i in range(n_classes):
            fpr[i], tpr[i], _ = roc_curve(y_test_bin[:, i], y_test_proba[:, i])
            roc_auc[i] = auc(fpr[i], tpr[i])
            color = color_map(i % 10)
            axes[1].plot(fpr[i], tpr[i], label=f'{class_names[i]}\n' +
                         f'(AUC={roc_auc[i]:.2f})', color=color)
            axes[1].plot([0, 1], [0, 1], 'k--', label='Random', linewidth=1)
            axes[1].set_title(f'ROC Curve\n{name + label_suffix}', font-size=12)
            axes[1].set_xlabel("False Positive Rate")
            axes[1].set_ylabel("True Positive Rate")
            axes[1].legend(font-size=9)
            axes[1].grid(True)
    else:
        axes[1].axis('off')
        axes[1].text(0.5, 0.5, 'No Probabilities\nAvailable for ROC',
                     ha='center', va='center', font-size=12)

    plt.tight_layout()
    plt.show()

model_index += 1

return pd.DataFrame(results)

```

9.7 Modelling without *StandardScaler*

9.7.1 Split Train and Test Data without *StandardScaler*

```
[ ]: X = features.drop(['Emotions', 'Emotion_Label'], axis=1)
y = features['Emotion_Label']

class_names = label_encoder.classes_
n_classes = len(class_names)

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

```
[ ]: X_train.shape
```

```
[ ]: (1200, 17)
```

```
[ ]: X_test.shape
```

```
[ ]: (300, 17)
```

```
[ ]: y_train.shape
```

```
[ ]: (1200,)
```

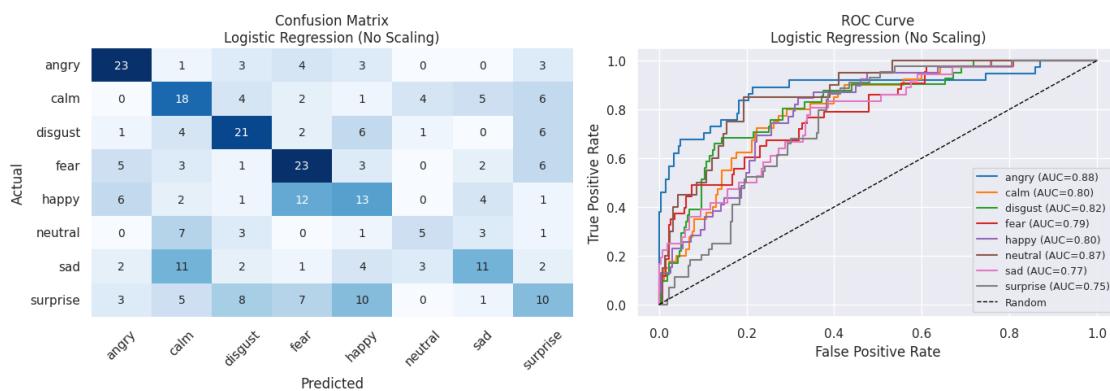
```
[ ]: y_test.shape
```

```
[ ]: (300,)
```

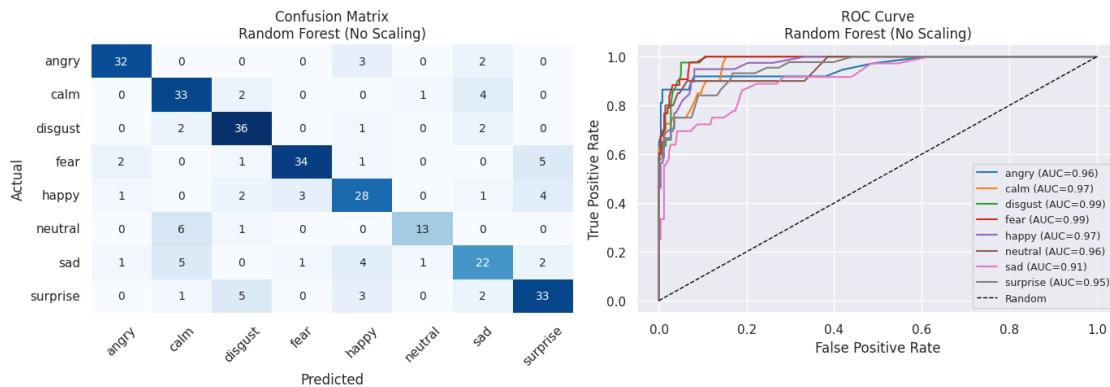
9.7.2 Train models and plot results without *StandardScaler*

```
[ ]: results_no_scaling = train_evaluate_and_plot(X_train, X_test, y_train, y_test, label_suffix=" (No Scaling)")
```

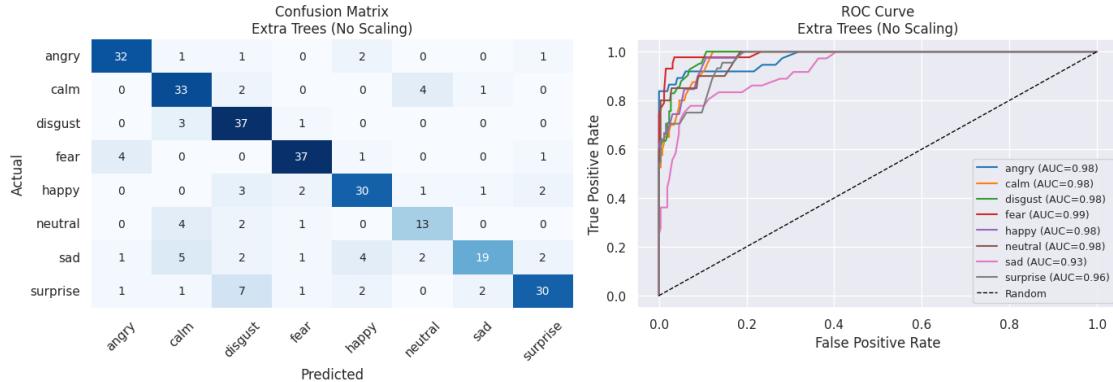
Training Logistic Regression (No Scaling)...



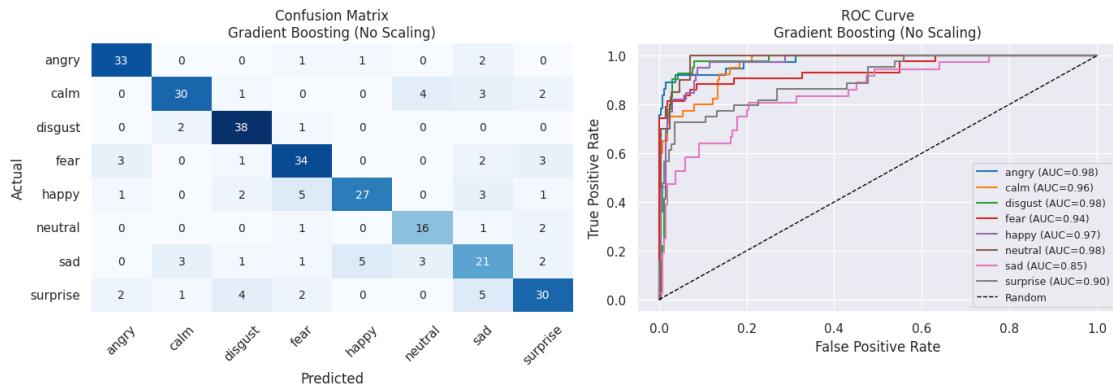
Training Random Forest (No Scaling)...



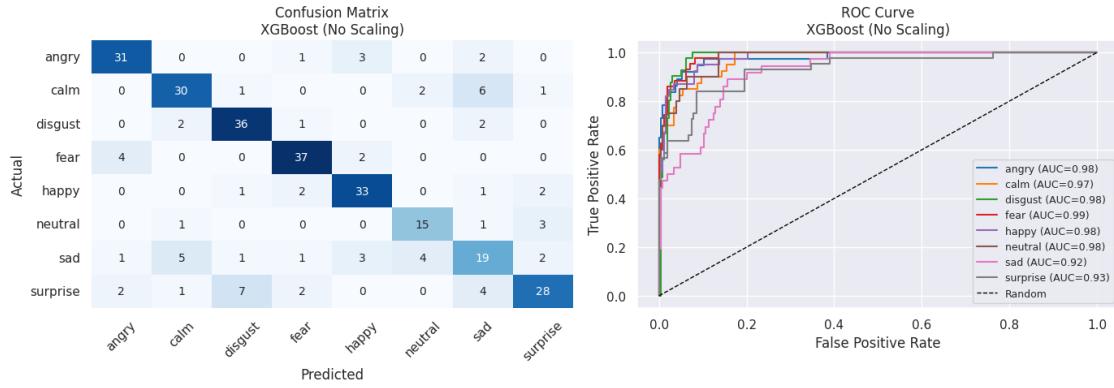
Training Extra Trees (No Scaling)...



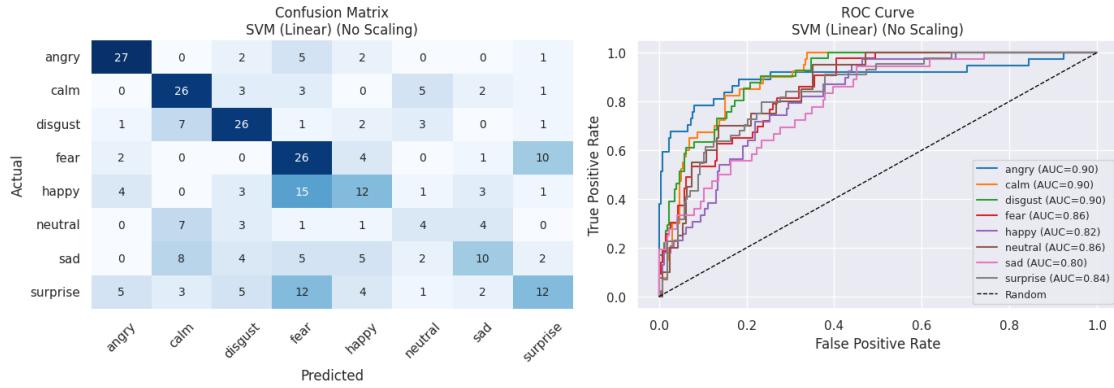
Training Gradient Boosting (No Scaling)...



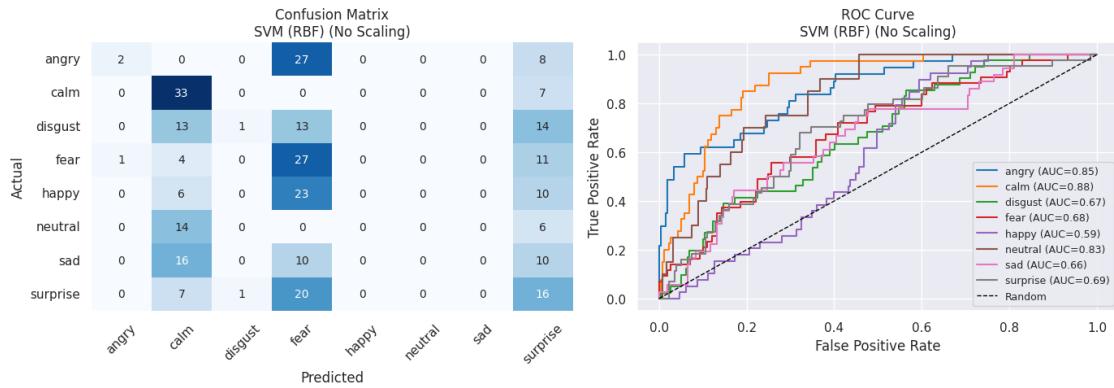
Training XGBoost (No Scaling)...



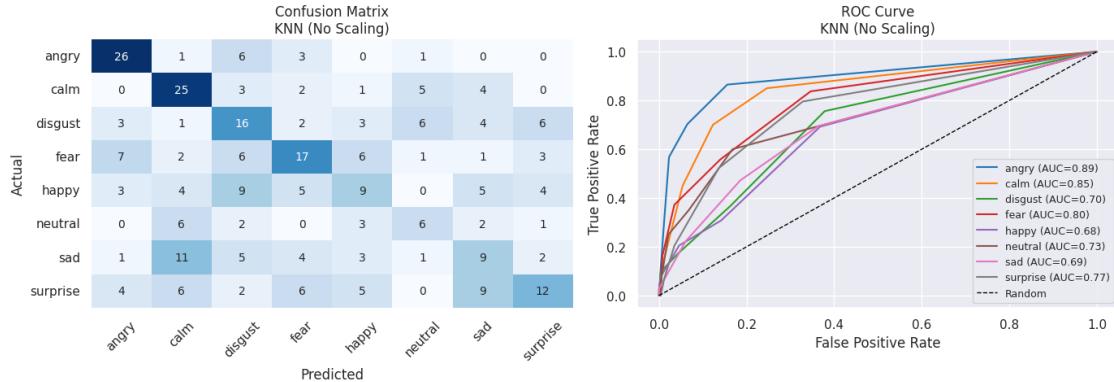
Training SVM (Linear) (No Scaling)...



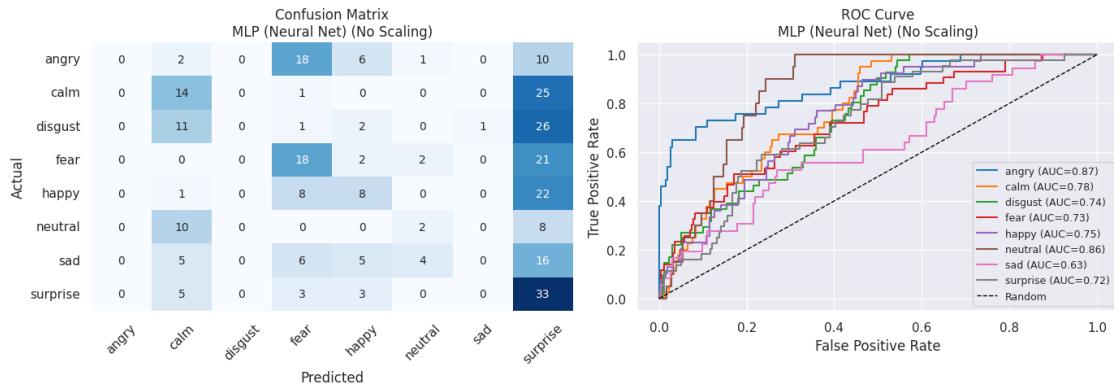
Training SVM (RBF) (No Scaling)...



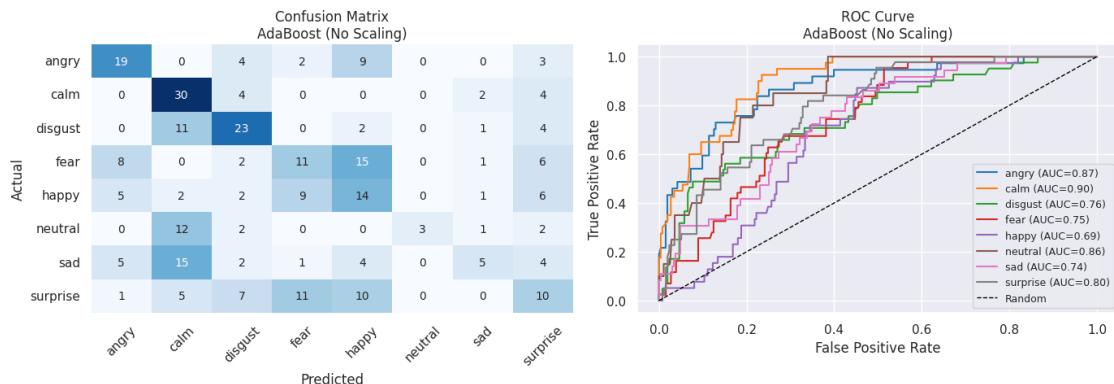
Training KNN (No Scaling)...



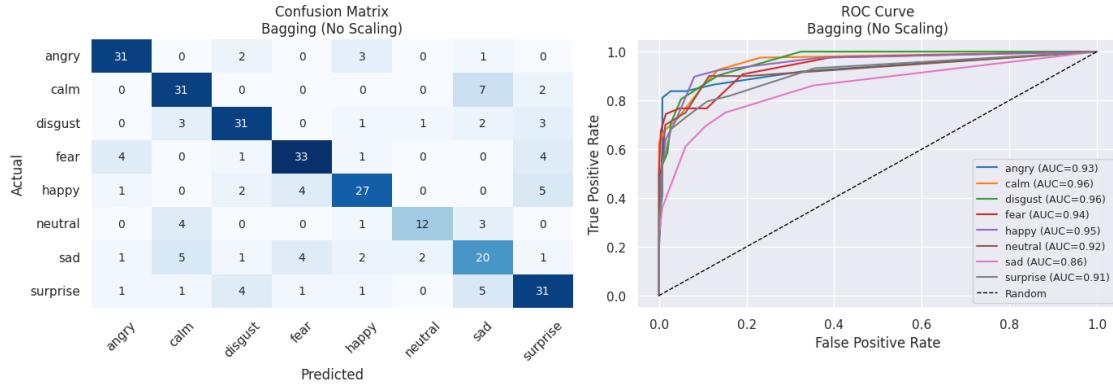
Training MLP (Neural Net) (No Scaling)...



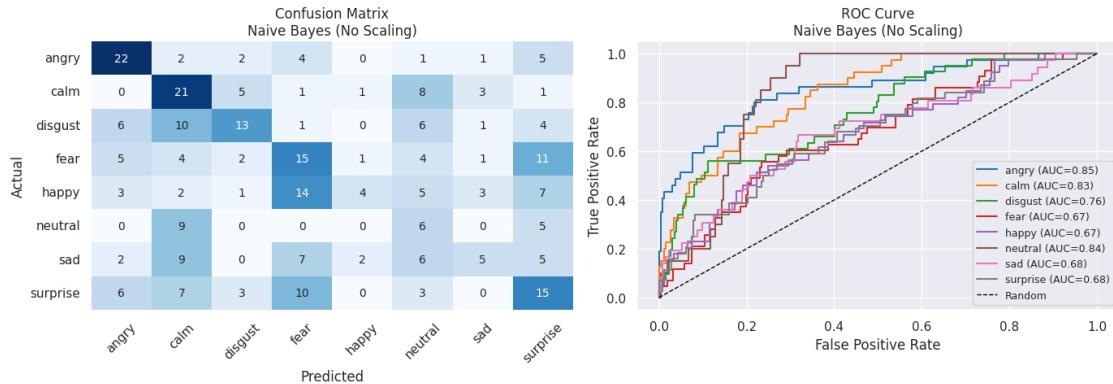
Training AdaBoost (No Scaling)...



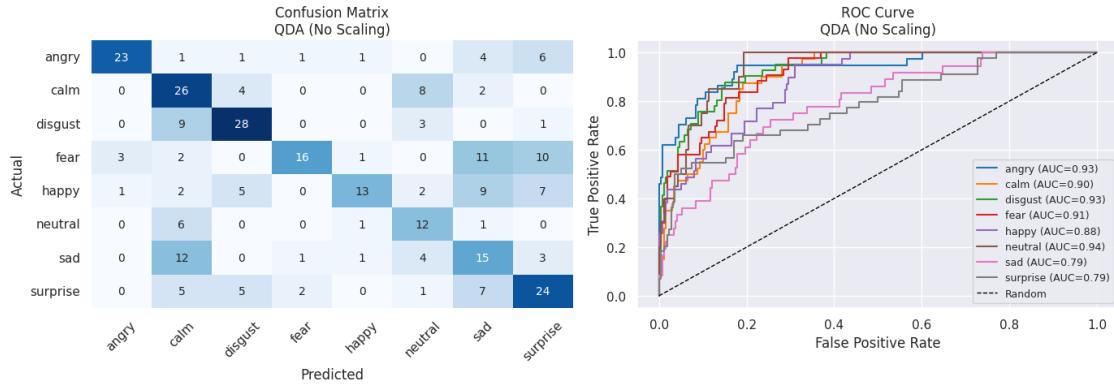
Training Bagging (No Scaling)...



Training Naive Bayes (No Scaling)...



Training QDA (No Scaling)...



Training LightGBM (No Scaling)...

[LightGBM] [Info] Auto-choosing col-wise multi-threading, the overhead of testing was 0.000465 seconds.

You can set `force_col_wise=true` to remove the overhead.

[LightGBM] [Info] Total Bins 4160

[LightGBM] [Info] Number of data points in the train set: 1200, number of used features: 17

[LightGBM] [Info] Start training from score -2.106470

[LightGBM] [Info] Start training from score -2.002481

[LightGBM] [Info] Start training from score -1.996327

[LightGBM] [Info] Start training from score -1.954278

[LightGBM] [Info] Start training from score -2.033831

[LightGBM] [Info] Start training from score -2.720629

[LightGBM] [Info] Start training from score -2.113343

[LightGBM] [Info] Start training from score -1.908293

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

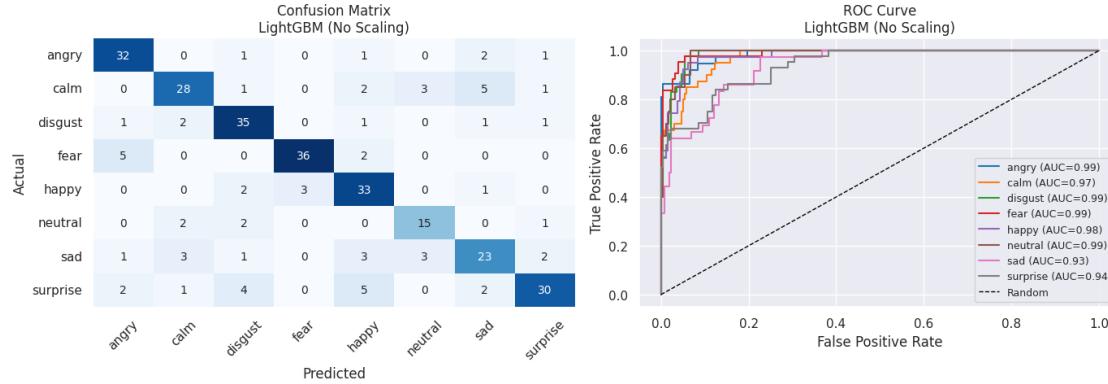
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

```
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
```



9.8 Modelling with *StandardScaler*

9.8.1 Split Train and Test Data with *StandardScaler*

```
[ ]: scaler = StandardScaler()
X_scaled = scaler.fit_transform(X)
X_train_scaled, X_test_scaled, y_train_scaled, y_test_scaled =
    train_test_split(X_scaled, y, test_size=0.2, random_state=42, stratify=y)

[ ]: X_train_scaled.shape
```

```
[ ]: (1200, 17)
```

```
[ ]: X_test_scaled.shape
```

```
[ ]: (300, 17)
```

```
[ ]: y_train_scaled.shape
```

```
[ ]: (1200,)
```

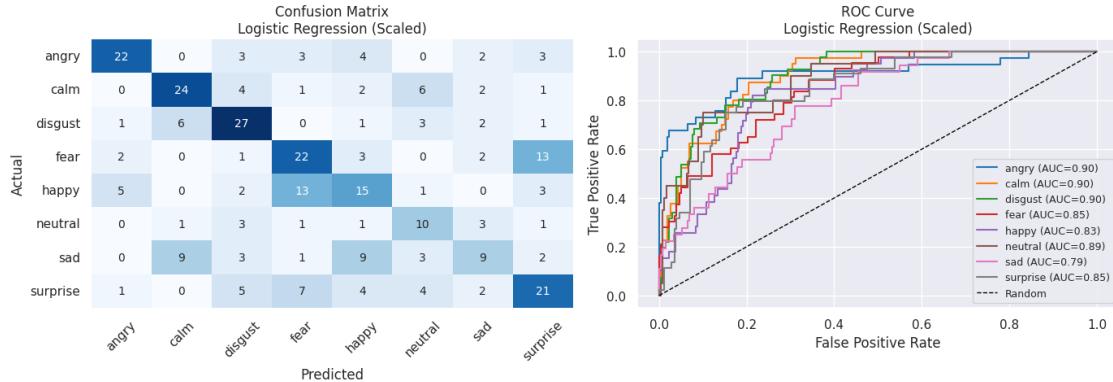
```
[ ]: y_test_scaled.shape
```

```
[ ]: (300,)
```

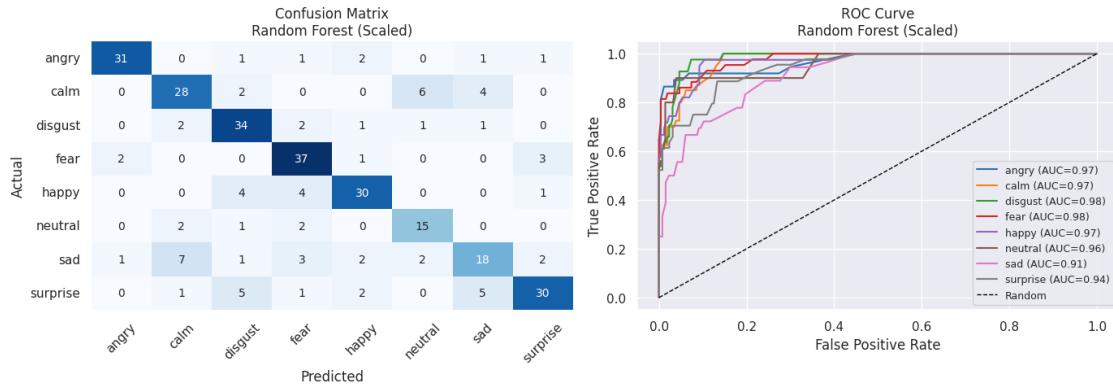
9.8.2 Train models and plot results with *StandardScaler*

```
[ ]: results_scaled = train_evaluate_and_plot(X_train_scaled, X_test_scaled, y_train_scaled, y_test_scaled, label_suffix=" (Scaled)")
```

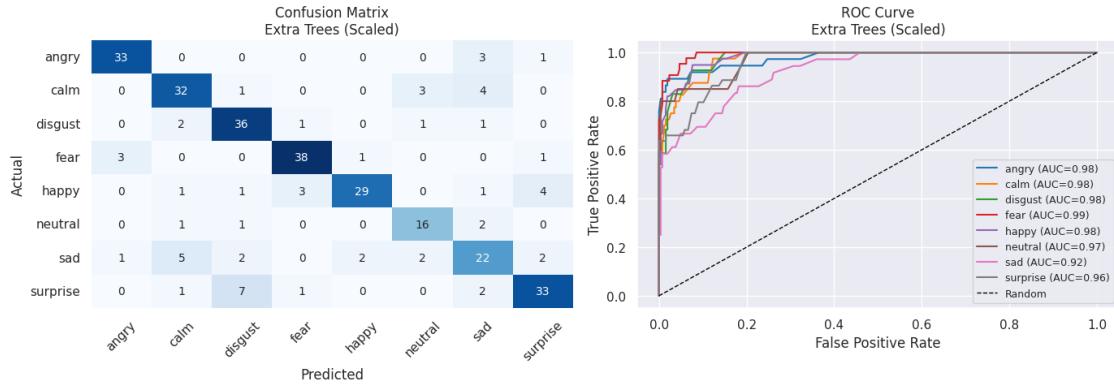
Training Logistic Regression (Scaled)...



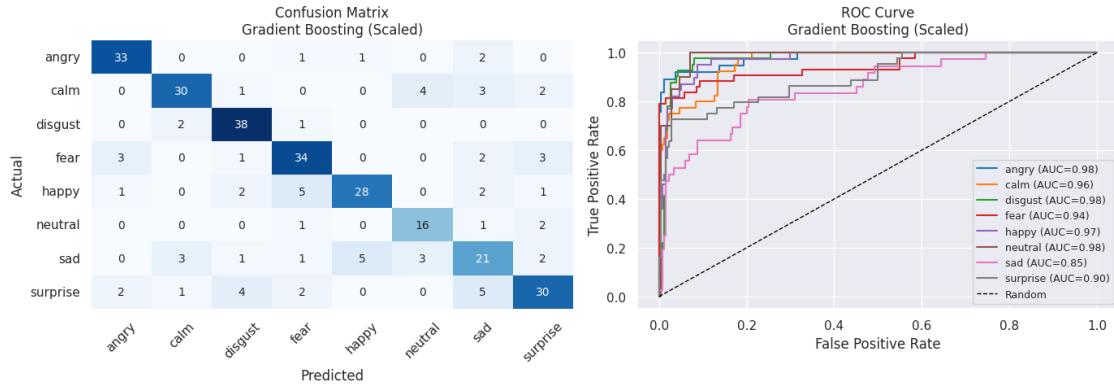
Training Random Forest (Scaled)...



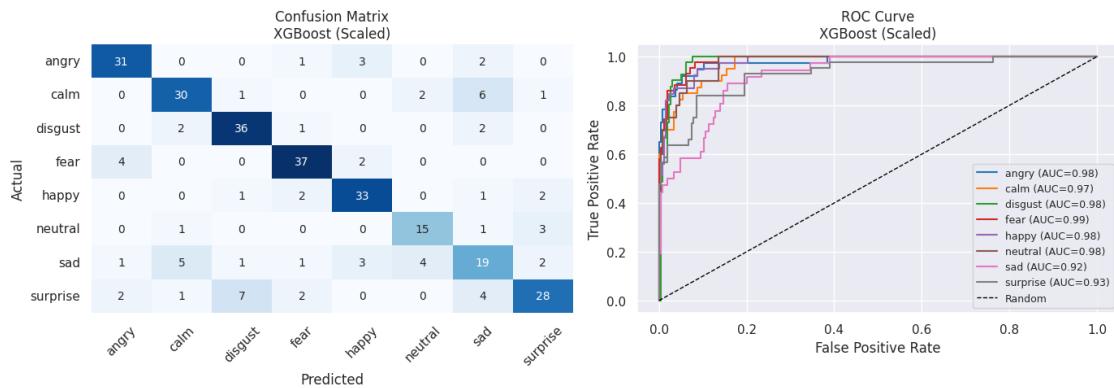
Training Extra Trees (Scaled)...



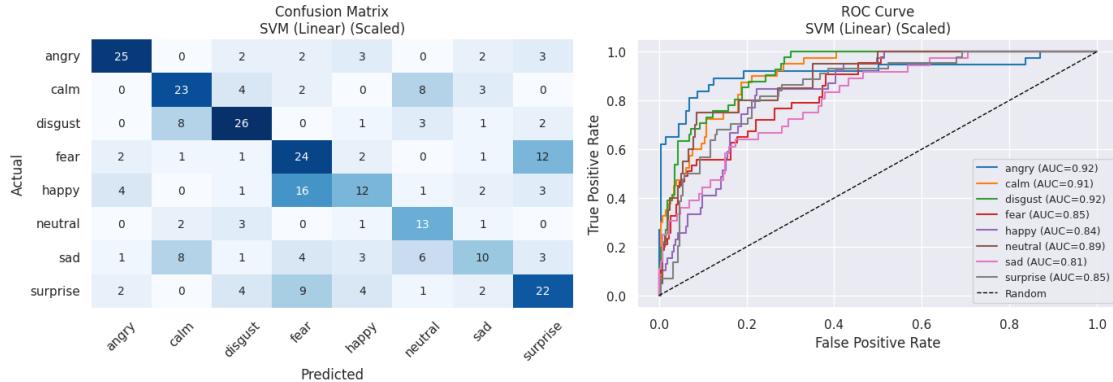
Training Gradient Boosting (Scaled)...



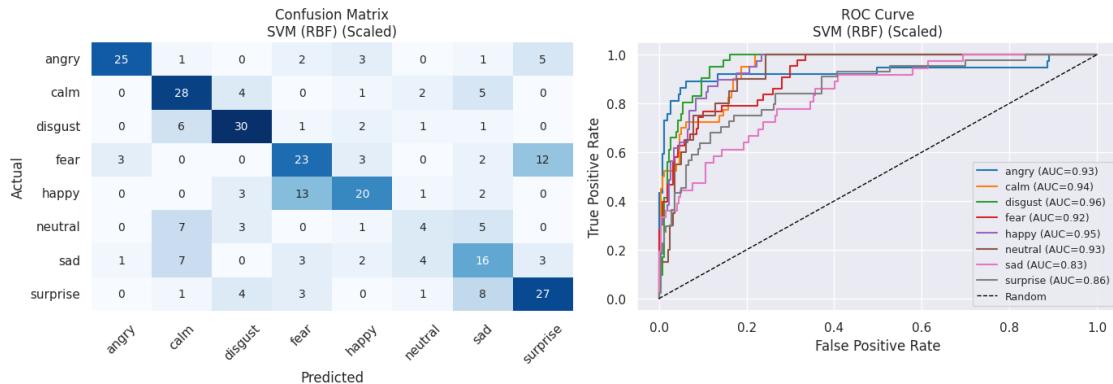
Training XGBoost (Scaled)...



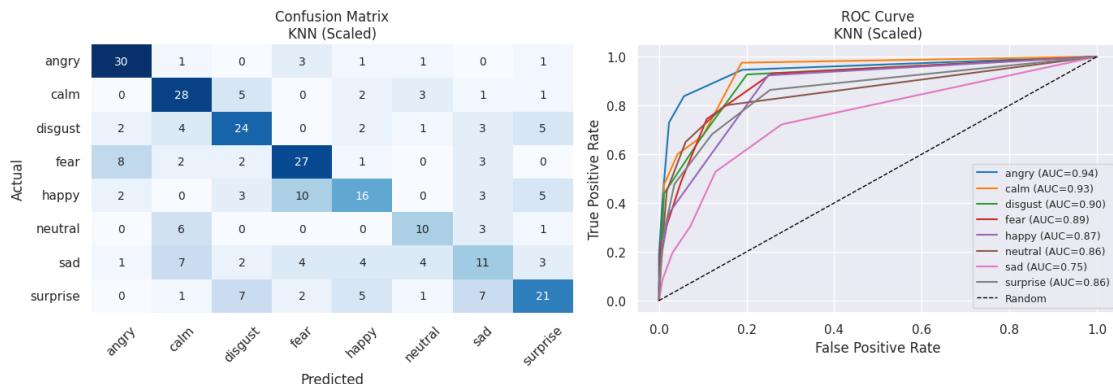
Training SVM (Linear) (Scaled)...



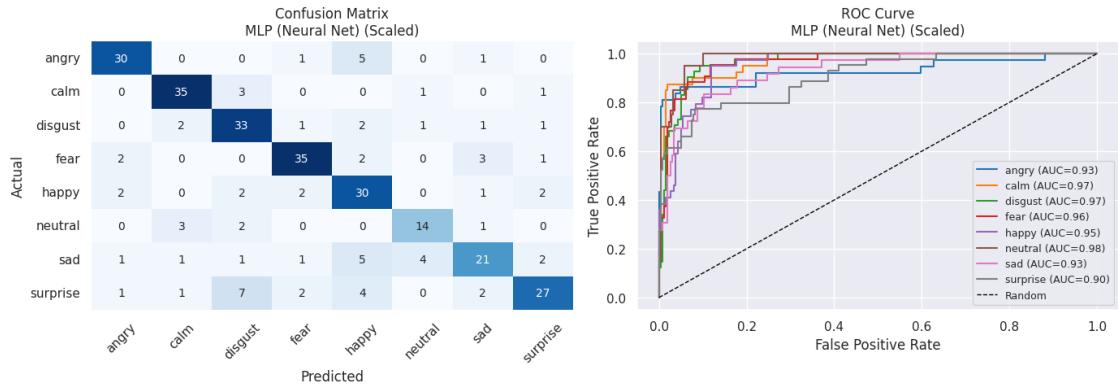
Training SVM (RBF) (Scaled)...



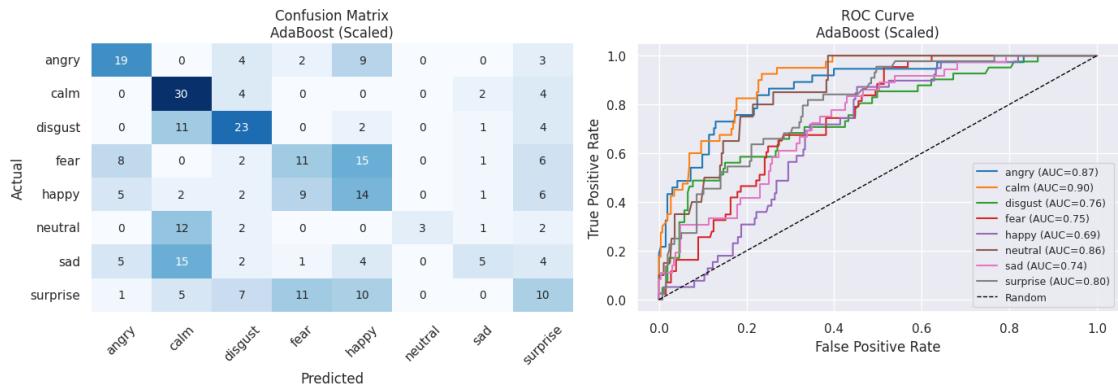
Training KNN (Scaled)...



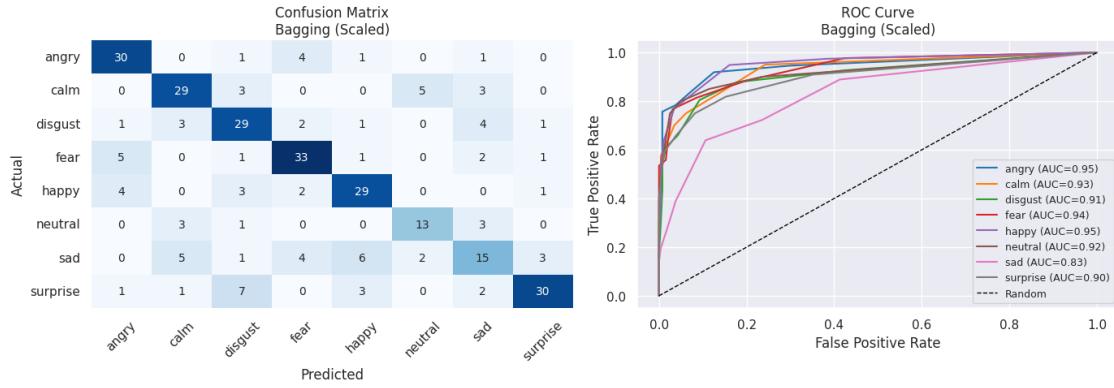
Training MLP (Neural Net) (Scaled)...



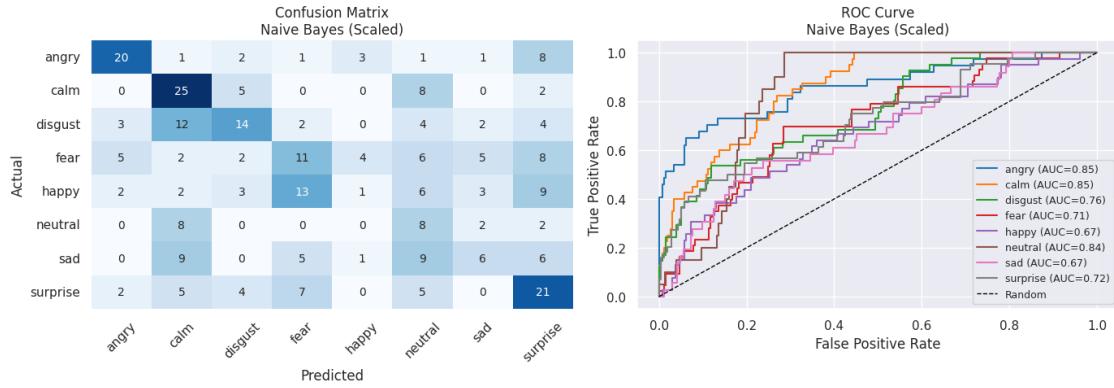
Training AdaBoost (Scaled)...



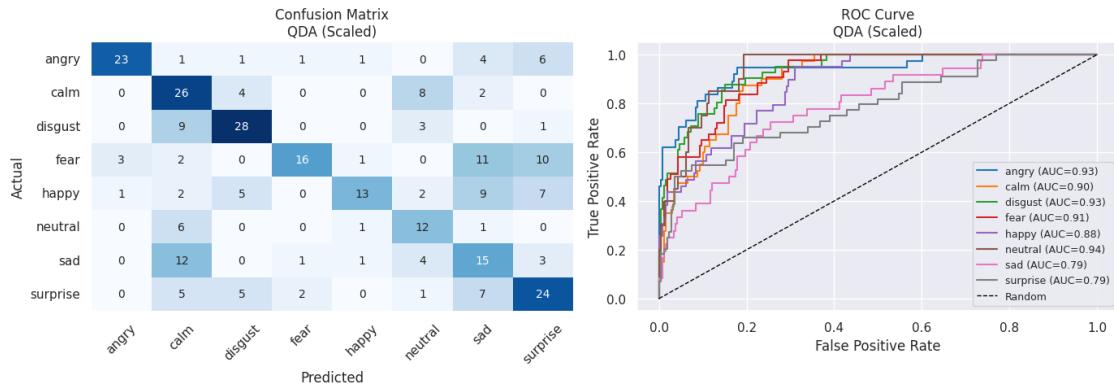
Training Bagging (Scaled)...



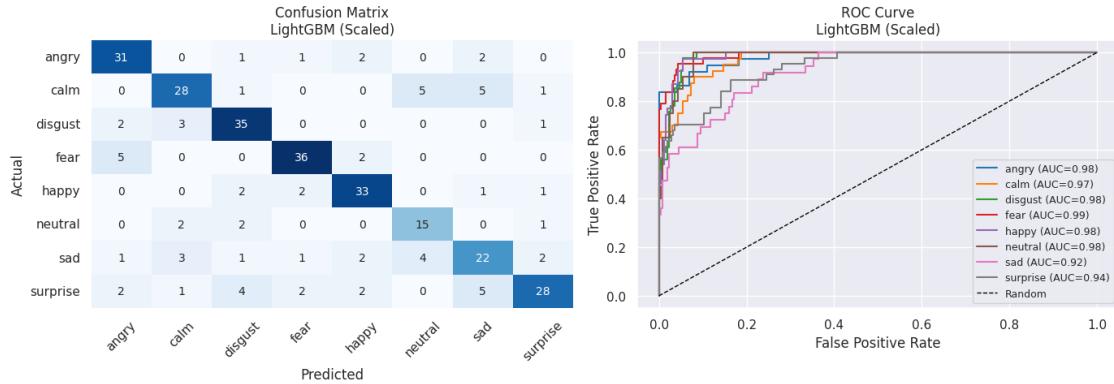
Training Naive Bayes (Scaled)...



Training QDA (Scaled)...



```
Training LightGBM (Scaled)...
[LightGBM] [Info] Auto-choosing col-wise multi-threading, the overhead of
testing was 0.000493 seconds.
You can set `force_col_wise=true` to remove the overhead.
[LightGBM] [Info] Total Bins 4159
[LightGBM] [Info] Number of data points in the train set: 1200, number of used
features: 17
[LightGBM] [Info] Start training from score -2.106470
[LightGBM] [Info] Start training from score -2.002481
[LightGBM] [Info] Start training from score -1.996327
[LightGBM] [Info] Start training from score -1.954278
[LightGBM] [Info] Start training from score -2.033831
[LightGBM] [Info] Start training from score -2.720629
[LightGBM] [Info] Start training from score -2.113343
[LightGBM] [Info] Start training from score -1.908293
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf
```



10 Visualization of combined results (without *StandardScaler* and with *StandardScaler*)

- I concatenated all the results of the models with scaling and the models without scaling using `pd.concat`.
- I looked at all the models from three angles:
 - Accuracy
 - Loss
 - Precision
 - Recall
 - F1 Score
- I created bar plots:
 - the first column for each model was the metrics from models with no scaling
 - the second column was the metrics from models that had scaling
 - I used distinct color bars for different metrics.
 - I displayed the metrics for train and test data in a side by side comparison
- I situated a performance increase or drop due to scaling across all models.
- I prepared ladder and waterfall plots:
 - I only looked at the test results for the scaled models in these plots.
 - The models were sorted from best to worst, based on metric.
 - Ladder plot demonstrates stepwise comparison.
 - Waterfall plot shows accumulated contributions.
- Analytics was done looking at which models that had a performance increase due to scaling, namely Extra Trees stood out as all performing better in the scaled mode.

```
[ ]: combined_ml_model_results = pd.concat([results_no_scaling, results_scaled])
```

```
[ ]: combined_ml_model_results
```

```
[ ]:          Model    Set  Accuracy     Loss  Precision  \
0  Logistic Regression (No Scaling)  Train  0.456667  0.543333  0.447270
1  Logistic Regression (No Scaling)  Test   0.413333  0.586667  0.408895
```

2	Random Forest (No Scaling)	Train	1.000000	0.000000	1.000000
3	Random Forest (No Scaling)	Test	0.770000	0.230000	0.774951
4	Extra Trees (No Scaling)	Train	1.000000	0.000000	1.000000
5	Extra Trees (No Scaling)	Test	0.770000	0.230000	0.779138
6	Gradient Boosting (No Scaling)	Train	0.997500	0.002500	0.997516
7	Gradient Boosting (No Scaling)	Test	0.763333	0.236667	0.765111
8	XGBoost (No Scaling)	Train	1.000000	0.000000	1.000000
9	XGBoost (No Scaling)	Test	0.763333	0.236667	0.762135
10	SVM (Linear) (No Scaling)	Train	0.566667	0.433333	0.563705
11	SVM (Linear) (No Scaling)	Test	0.476667	0.523333	0.471478
12	SVM (RBF) (No Scaling)	Train	0.269167	0.730833	0.209335
13	SVM (RBF) (No Scaling)	Test	0.263333	0.736667	0.258735
14	KNN (No Scaling)	Train	0.594167	0.405833	0.597091
15	KNN (No Scaling)	Test	0.400000	0.600000	0.393129
16	MLP (Neural Net) (No Scaling)	Train	0.285000	0.715000	0.319664
17	MLP (Neural Net) (No Scaling)	Test	0.250000	0.750000	0.170675
18	AdaBoost (No Scaling)	Train	0.384167	0.615833	0.408434
19	AdaBoost (No Scaling)	Test	0.383333	0.616667	0.422229
20	Bagging (No Scaling)	Train	0.995000	0.005000	0.995051
21	Bagging (No Scaling)	Test	0.720000	0.280000	0.723338
22	Naive Bayes (No Scaling)	Train	0.358333	0.641667	0.396380
23	Naive Bayes (No Scaling)	Test	0.336667	0.663333	0.374719
24	QDA (No Scaling)	Train	0.645000	0.355000	0.694961
25	QDA (No Scaling)	Test	0.523333	0.476667	0.595580
26	LightGBM (No Scaling)	Train	1.000000	0.000000	1.000000
27	LightGBM (No Scaling)	Test	0.773333	0.226667	0.778551
0	Logistic Regression (Scaled)	Train	0.559167	0.440833	0.557897
1	Logistic Regression (Scaled)	Test	0.500000	0.500000	0.502323
2	Random Forest (Scaled)	Train	1.000000	0.000000	1.000000
3	Random Forest (Scaled)	Test	0.743333	0.256667	0.746356
4	Extra Trees (Scaled)	Train	1.000000	0.000000	1.000000
5	Extra Trees (Scaled)	Test	0.796667	0.203333	0.800529
6	Gradient Boosting (Scaled)	Train	0.997500	0.002500	0.997516
7	Gradient Boosting (Scaled)	Test	0.766667	0.233333	0.767698
8	XGBoost (Scaled)	Train	1.000000	0.000000	1.000000
9	XGBoost (Scaled)	Test	0.763333	0.236667	0.762135
10	SVM (Linear) (Scaled)	Train	0.596667	0.403333	0.598028
11	SVM (Linear) (Scaled)	Test	0.516667	0.483333	0.521989
12	SVM (RBF) (Scaled)	Train	0.760000	0.240000	0.767457
13	SVM (RBF) (Scaled)	Test	0.576667	0.423333	0.581448
14	KNN (Scaled)	Train	0.767500	0.232500	0.769070
15	KNN (Scaled)	Test	0.556667	0.443333	0.548900
16	MLP (Neural Net) (Scaled)	Train	0.970833	0.029167	0.970859
17	MLP (Neural Net) (Scaled)	Test	0.750000	0.250000	0.755679
18	AdaBoost (Scaled)	Train	0.384167	0.615833	0.408434
19	AdaBoost (Scaled)	Test	0.383333	0.616667	0.422229
20	Bagging (Scaled)	Train	0.995000	0.005000	0.995045

21	Bagging (Scaled)	Test	0.693333	0.306667	0.693330
22	Naive Bayes (Scaled)	Train	0.384167	0.615833	0.407180
23	Naive Bayes (Scaled)	Test	0.353333	0.646667	0.348392
24	QDA (Scaled)	Train	0.645000	0.355000	0.694961
25	QDA (Scaled)	Test	0.523333	0.476667	0.595580
26	LightGBM (Scaled)	Train	1.000000	0.000000	1.000000
27	LightGBM (Scaled)	Test	0.760000	0.240000	0.763509

	Recall	F1 Score
0	0.456667	0.447858
1	0.413333	0.407066
2	1.000000	1.000000
3	0.770000	0.769622
4	1.000000	1.000000
5	0.770000	0.766805
6	0.997500	0.997498
7	0.763333	0.762072
8	1.000000	1.000000
9	0.763333	0.761163
10	0.566667	0.558776
11	0.476667	0.462955
12	0.269167	0.176238
13	0.263333	0.169589
14	0.594167	0.588817
15	0.400000	0.390304
16	0.285000	0.210791
17	0.250000	0.183492
18	0.384167	0.363933
19	0.383333	0.362671
20	0.995000	0.995004
21	0.720000	0.720212
22	0.358333	0.341762
23	0.336667	0.324188
24	0.645000	0.640600
25	0.523333	0.528690
26	1.000000	1.000000
27	0.773333	0.772663
0	0.559167	0.557081
1	0.500000	0.496853
2	1.000000	1.000000
3	0.743333	0.741359
4	1.000000	1.000000
5	0.796667	0.796533
6	0.997500	0.997498
7	0.766667	0.765257
8	1.000000	1.000000
9	0.763333	0.761163

```

10 0.596667 0.594206
11 0.516667 0.511296
12 0.760000 0.756780
13 0.576667 0.574752
14 0.767500 0.766909
15 0.556667 0.549671
16 0.970833 0.970816
17 0.750000 0.748802
18 0.384167 0.363933
19 0.383333 0.362671
20 0.995000 0.994998
21 0.693333 0.691085
22 0.384167 0.360738
23 0.353333 0.334702
24 0.645000 0.640600
25 0.523333 0.528690
26 1.000000 1.000000
27 0.760000 0.758747

```

10.1 Bar Plots of all models (1st column: without scaling and 2nd column: with scaling)

```

[ ]: # Define colors for each metric
metric_colors = {
    'Accuracy': 'tab:blue',
    'Loss': 'tab:red',
    'Precision': 'tab:green',
    'Recall': 'tab:purple',
    'F1 Score': 'tab:orange'
}

models = combined_ml_model_results[combined_ml_model_results['Model'].str.
    ~contains('No Scaling')]['Model'].str.replace(' (No Scaling)', '').unique()
metrics = ['Accuracy', 'Loss', 'Precision', 'Recall', 'F1 Score']
sets = ['Train', 'Test']

fig, axes = plt.subplots(len(models), 2, figsize=(18, 7 * len(models)))
fig.tight_layout(pad=5.0)

for i, model in enumerate(models):
    for j, scaling in enumerate(['No Scaling', 'Scaled']):
        ax = axes[i, j] if len(models) > 1 else axes[j]
        model_name = f"{model} ({scaling})"
        data = combined_ml_model_results[combined_ml_model_results['Model'] == model_name]

```

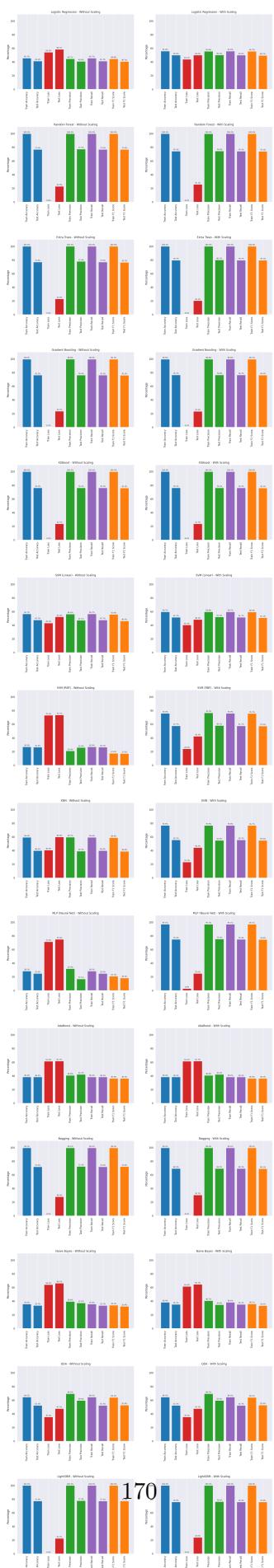
```

# Prepare data for plotting
values = []
labels = []
bar_colors = []
for metric in metrics:
    for set_type in sets:
        row = data[data['Set'] == set_type]
        if not row.empty:
            value = row.iloc[0][metric]
            values.append(value * 100) # Convert to percentage
            labels.append(f"{set_type} {metric}")
            bar_colors.append(metric_colors[metric])

# Plot
bars = ax.bar(labels, values, color=bar_colors)
ax.set_ylim(0, 110)
ax.set_ylabel('Percentage')
ax.set_title(f'{model} - {'Without Scaling' if scaling == 'No Scaling' else 'With Scaling'}')
ax.bar_label(bars, fmt='%.1f%%', padding=3, fontsize=8)
ax.tick_params(axis='x', rotation=90)
ax.grid(axis='y', linestyle='--', alpha=0.7)

plt.subplots_adjust(hspace=0.5)
plt.show()

```



10.2 Visualize the best model of scaled ones in 2 different plots (1st column: ladder plot and 2nd column: scatter plot)

```
[ ]: # Prepare DataFrame as before
combined_ml_model_results_copy = combined_ml_model_results.copy()
combined_ml_model_results_copy_test =(combined_ml_model_results_copy[combined_ml_model_results_copy["Set"] == "Test"].copy())
combined_ml_model_results_copy_test["Scaled"] =combined_ml_model_results_copy_test["Model"].str.contains("Scaled")
combined_ml_model_results_copy_test["Model Name"] =combined_ml_model_results_copy_test["Model"].str.replace(r" \(\Scaled\)| \(No Scaling\)", "", regex=True)

# Only scaled models
df_scaled =combined_ml_model_results_copy_test[combined_ml_model_results_copy_test["Scaled"]].copy()

# Metrics and their colors
metrics = [
    ("Accuracy", "Accuracy (%)", "green"),
    ("Precision", "Precision (%)", "blue"),
    ("Loss", "Loss", "#ff9999"), # light red
    ("Recall", "Recall (%)", "orange"),
    ("F1 Score", "F1 Score (%)", "purple")]
]

fig, axes = plt.subplots(len(metrics), 2, figsize=(20, 28))
plt.subplots_adjust(hspace=0.35)

for i, (metric, metric_label, metric_color) in enumerate(metrics):
    # Sort models by metric (best to worst)
    ascending = True if metric == "Loss" else False
    df_metric = df_scaled.sort_values(metric, ascending=ascending).reset_index(drop=True)
    model_names = df_metric["Model Name"].tolist()
    metric_values = df_metric[metric].values
    y_pos = np.arange(len(model_names))

    # For percentage metrics, scale to 0-100
    if metric != "Loss":
        display_values = metric_values * 100
        value_fmt = "{:.2f}%"
    else:
```

```

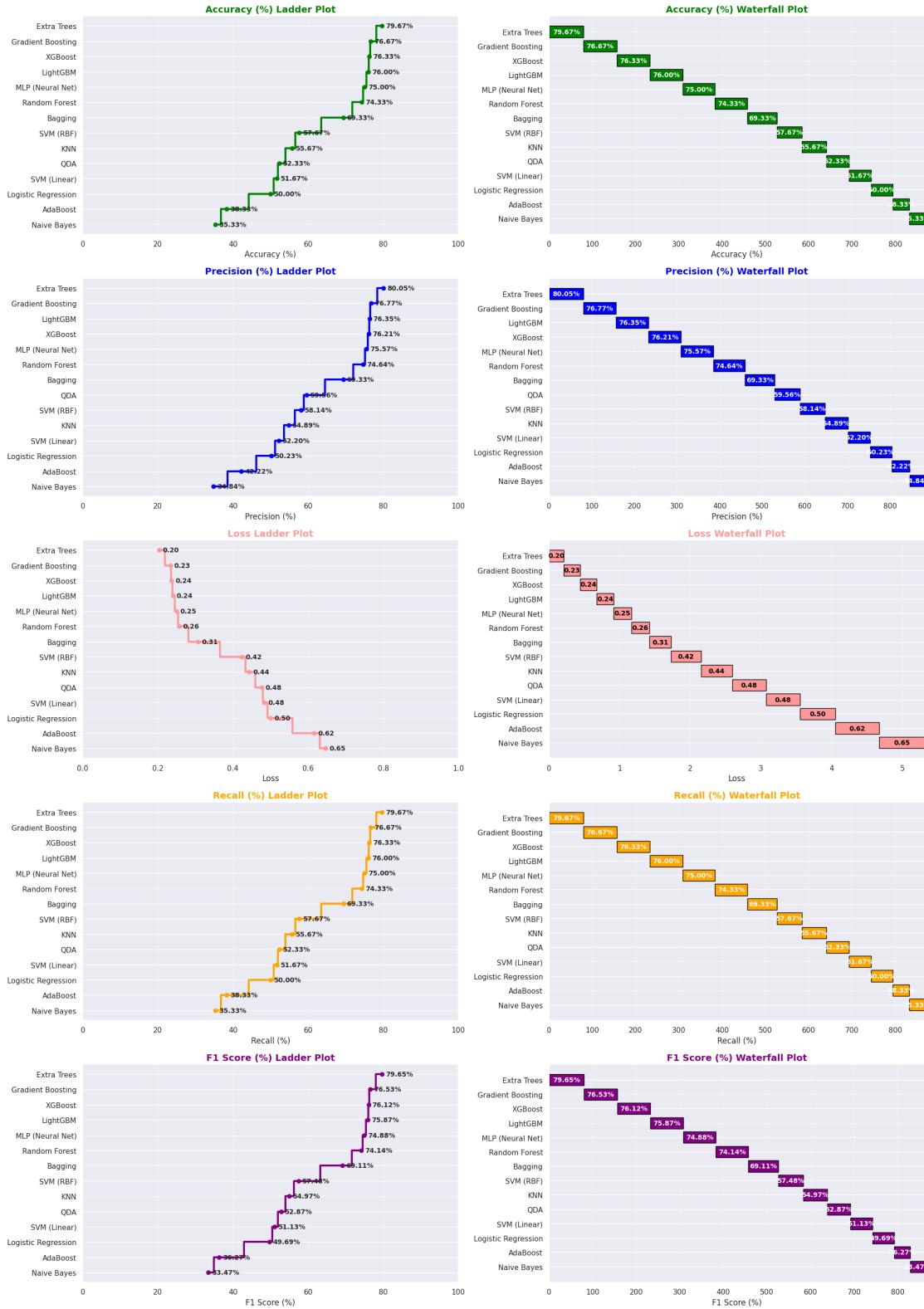
        xlim = (0, 100)
    else:
        display_values = metric_values
        value_fmt = "{:.2f}"
        xlim = (0, 1)

    # --- Ladder (step) plot ---
    ax1 = axes[i, 0]
    ax1.step(display_values, y_pos, where='mid', linewidth=3, □
    ↪color=metric_color, marker='o')
    for idx, (val, label) in enumerate(zip(display_values, model_names)):
        ax1.text(val + (1 if metric != "Loss" else 0.01), idx, value_fmt.
    ↪format(val), va="center", fontsize=10, fontweight='bold')
    ax1.set_yticks(y_pos)
    ax1.set_yticklabels(model_names)
    ax1.set_title(f"{metric_label} Ladder Plot", fontsize=14, □
    ↪fontweight='bold', color=metric_color)
    ax1.set_xlabel(metric_label)
    ax1.set_xlim(xlim)
    ax1.invert_yaxis()
    ax1.grid(axis='x', linestyle='--', alpha=0.5)

    # --- Waterfall plot ---
    ax2 = axes[i, 1]
    cumulative = np.insert(np.cumsum(display_values[:-1]), 0, 0)
    for idx, (val, base) in enumerate(zip(display_values, cumulative)):
        ax2.barh(model_names[idx], val, left=base, color=metric_color, □
    ↪edgecolor='black')
        ax2.text(base + val/2, idx, value_fmt.format(val), va="center", □
    ↪ha="center", fontsize=10, fontweight='bold', color='white' if abs(val) > 10 □
    ↪else 'black')
    ax2.set_title(f"{metric_label} Waterfall Plot", fontsize=14, □
    ↪fontweight='bold', color=metric_color)
    ax2.set_xlabel(metric_label)
    ax2.set_xlim(0, cumulative[-1] + display_values[-1])
    ax2.invert_yaxis()
    ax2.grid(axis='x', linestyle='--', alpha=0.5)

plt.tight_layout()
plt.show()

```



11 Train the same with Basic Deep Learning Models

Let us understand this table of what kind of Deep Learning models I trained here.

Model Name	Architecture Layers	Key Regularization Techniques	Loss Function	Batch Size	Output Activation
BasicNN	Dense(128, ReLU) → Dropout(0.3) → Dense(64, ReLU) → Dropout(0.3)	Dropout(0.3) Shallow network	Adam Categorical Crossentropy	50	16 Softmax
DeepNN	Dense(128, ReLU) → Dropout(0.4) → Dense(128, ReLU) → Dropout(0.3) → Dense(64, ReLU)	Dropout(0.4) 0.3) Deep network with heavy regularization	Adam Categorical Crossentropy	50	16 Softmax
BN_Activate	ReLU → Dropout(0.3) → Dense(128) → BN → ReLU → Dropout(0.3) → Dense(64, ReLU)	Dropout(0.3) Batch Normalization + ReLU activations	Adam Categorical Crossentropy	50	16 Softmax

All models used one-hot encoded labels and were validated on the test set using: - Accuracy - Validation Accuracy - Loss - Validation Loss

The history of each training run was stored in the `histories` list for later evaluation.

```
[ ]: y_train_nn = to_categorical(y_train_scaled)
y_test_nn = to_categorical(y_test_scaled)

histories = []
```

11.1 Shallow network with two dense layers and dropout

```
[ ]: model1 = Sequential()
model1.add(Dense(128, activation='relu', input_shape=(X_train_scaled.
    ↪shape[1],)))
model1.add(Dropout(0.3))
model1.add(Dense(64, activation='relu'))
model1.add(Dropout(0.3))
model1.add(Dense(y_train_nn.shape[1], activation='softmax'))

model1.compile(optimizer='adam', loss='categorical_crossentropy',
    ↪metrics=['accuracy'])

history1 = model1.fit(X_train_scaled, y_train_nn,
    validation_data=(X_test_scaled, y_test_nn),
    epochs=50, batch_size=16, verbose=1)
```

```
histories.append(('BasicNN_Dropout', history1))
```

```
Epoch 1/50
75/75      3s 9ms/step -
accuracy: 0.1851 - loss: 2.0890 - val_accuracy: 0.3633 - val_loss: 1.7351
Epoch 2/50
75/75      1s 4ms/step -
accuracy: 0.3247 - loss: 1.7573 - val_accuracy: 0.4100 - val_loss: 1.5609
Epoch 3/50
75/75      0s 3ms/step -
accuracy: 0.3888 - loss: 1.6165 - val_accuracy: 0.4367 - val_loss: 1.4632
Epoch 4/50
75/75      0s 4ms/step -
accuracy: 0.4179 - loss: 1.5394 - val_accuracy: 0.4567 - val_loss: 1.3911
Epoch 5/50
75/75      0s 4ms/step -
accuracy: 0.4615 - loss: 1.4665 - val_accuracy: 0.4767 - val_loss: 1.3330
Epoch 6/50
75/75      0s 4ms/step -
accuracy: 0.4797 - loss: 1.4104 - val_accuracy: 0.4767 - val_loss: 1.2943
Epoch 7/50
75/75      1s 4ms/step -
accuracy: 0.5150 - loss: 1.3410 - val_accuracy: 0.5233 - val_loss: 1.2468
Epoch 8/50
75/75      0s 3ms/step -
accuracy: 0.5387 - loss: 1.2931 - val_accuracy: 0.5333 - val_loss: 1.2168
Epoch 9/50
75/75      0s 5ms/step -
accuracy: 0.5547 - loss: 1.2728 - val_accuracy: 0.5467 - val_loss: 1.2134
Epoch 10/50
75/75      1s 4ms/step -
accuracy: 0.5400 - loss: 1.2905 - val_accuracy: 0.5433 - val_loss: 1.1908
Epoch 11/50
75/75      0s 4ms/step -
accuracy: 0.5277 - loss: 1.2437 - val_accuracy: 0.5633 - val_loss: 1.1671
Epoch 12/50
75/75      0s 4ms/step -
accuracy: 0.5718 - loss: 1.1680 - val_accuracy: 0.5633 - val_loss: 1.1576
Epoch 13/50
75/75      0s 4ms/step -
accuracy: 0.5653 - loss: 1.2075 - val_accuracy: 0.5867 - val_loss: 1.1359
Epoch 14/50
75/75      0s 3ms/step -
accuracy: 0.6038 - loss: 1.1669 - val_accuracy: 0.5900 - val_loss: 1.1260
Epoch 15/50
75/75      0s 3ms/step -
```

```
accuracy: 0.5906 - loss: 1.1181 - val_accuracy: 0.6000 - val_loss: 1.1143
Epoch 16/50
75/75      0s 4ms/step -
accuracy: 0.5770 - loss: 1.1173 - val_accuracy: 0.5767 - val_loss: 1.1140
Epoch 17/50
75/75      0s 4ms/step -
accuracy: 0.6291 - loss: 1.0123 - val_accuracy: 0.5700 - val_loss: 1.1017
Epoch 18/50
75/75      0s 3ms/step -
accuracy: 0.5981 - loss: 1.0715 - val_accuracy: 0.5867 - val_loss: 1.0950
Epoch 19/50
75/75      0s 4ms/step -
accuracy: 0.6316 - loss: 1.0241 - val_accuracy: 0.6000 - val_loss: 1.0780
Epoch 20/50
75/75      1s 4ms/step -
accuracy: 0.6341 - loss: 1.0287 - val_accuracy: 0.5900 - val_loss: 1.0576
Epoch 21/50
75/75      0s 4ms/step -
accuracy: 0.6451 - loss: 0.9787 - val_accuracy: 0.5867 - val_loss: 1.0513
Epoch 22/50
75/75      0s 4ms/step -
accuracy: 0.6688 - loss: 0.9415 - val_accuracy: 0.5967 - val_loss: 1.0592
Epoch 23/50
75/75      0s 3ms/step -
accuracy: 0.6535 - loss: 0.9897 - val_accuracy: 0.6133 - val_loss: 1.0251
Epoch 24/50
75/75      0s 4ms/step -
accuracy: 0.6355 - loss: 0.9714 - val_accuracy: 0.6100 - val_loss: 1.0366
Epoch 25/50
75/75      0s 4ms/step -
accuracy: 0.6662 - loss: 0.9450 - val_accuracy: 0.5967 - val_loss: 1.0233
Epoch 26/50
75/75      0s 4ms/step -
accuracy: 0.6461 - loss: 0.9759 - val_accuracy: 0.6033 - val_loss: 1.0224
Epoch 27/50
75/75      1s 4ms/step -
accuracy: 0.6562 - loss: 0.9375 - val_accuracy: 0.5933 - val_loss: 1.0135
Epoch 28/50
75/75      1s 5ms/step -
accuracy: 0.6577 - loss: 0.9424 - val_accuracy: 0.6133 - val_loss: 1.0105
Epoch 29/50
75/75      1s 6ms/step -
accuracy: 0.6888 - loss: 0.8784 - val_accuracy: 0.6100 - val_loss: 1.0003
Epoch 30/50
75/75      1s 6ms/step -
accuracy: 0.6751 - loss: 0.8587 - val_accuracy: 0.6133 - val_loss: 0.9919
Epoch 31/50
75/75      1s 6ms/step -
```

```
accuracy: 0.6649 - loss: 0.8784 - val_accuracy: 0.6167 - val_loss: 0.9976
Epoch 32/50
75/75      1s 7ms/step -
accuracy: 0.6851 - loss: 0.8906 - val_accuracy: 0.6133 - val_loss: 0.9823
Epoch 33/50
75/75      0s 4ms/step -
accuracy: 0.6727 - loss: 0.8621 - val_accuracy: 0.6333 - val_loss: 0.9674
Epoch 34/50
75/75      0s 4ms/step -
accuracy: 0.7018 - loss: 0.8545 - val_accuracy: 0.6367 - val_loss: 0.9578
Epoch 35/50
75/75      1s 4ms/step -
accuracy: 0.7087 - loss: 0.8112 - val_accuracy: 0.6167 - val_loss: 0.9729
Epoch 36/50
75/75      0s 4ms/step -
accuracy: 0.7197 - loss: 0.7916 - val_accuracy: 0.6167 - val_loss: 0.9606
Epoch 37/50
75/75      0s 4ms/step -
accuracy: 0.6995 - loss: 0.8030 - val_accuracy: 0.6333 - val_loss: 0.9596
Epoch 38/50
75/75      0s 4ms/step -
accuracy: 0.7166 - loss: 0.7693 - val_accuracy: 0.6300 - val_loss: 0.9375
Epoch 39/50
75/75      1s 4ms/step -
accuracy: 0.7333 - loss: 0.7724 - val_accuracy: 0.6500 - val_loss: 0.9413
Epoch 40/50
75/75      1s 3ms/step -
accuracy: 0.7157 - loss: 0.7734 - val_accuracy: 0.6367 - val_loss: 0.9374
Epoch 41/50
75/75      0s 3ms/step -
accuracy: 0.7090 - loss: 0.8056 - val_accuracy: 0.6500 - val_loss: 0.9310
Epoch 42/50
75/75      0s 4ms/step -
accuracy: 0.7509 - loss: 0.7241 - val_accuracy: 0.6400 - val_loss: 0.9470
Epoch 43/50
75/75      1s 3ms/step -
accuracy: 0.7142 - loss: 0.7995 - val_accuracy: 0.6367 - val_loss: 0.9221
Epoch 44/50
75/75      0s 4ms/step -
accuracy: 0.7129 - loss: 0.7815 - val_accuracy: 0.6667 - val_loss: 0.9193
Epoch 45/50
75/75      0s 3ms/step -
accuracy: 0.7450 - loss: 0.7330 - val_accuracy: 0.6333 - val_loss: 0.9332
Epoch 46/50
75/75      0s 3ms/step -
accuracy: 0.7227 - loss: 0.7488 - val_accuracy: 0.6600 - val_loss: 0.9297
Epoch 47/50
75/75      0s 4ms/step -
```

```

accuracy: 0.7410 - loss: 0.7308 - val_accuracy: 0.6467 - val_loss: 0.9114
Epoch 48/50
75/75      0s 3ms/step -
accuracy: 0.7594 - loss: 0.7209 - val_accuracy: 0.6667 - val_loss: 0.9151
Epoch 49/50
75/75      0s 4ms/step -
accuracy: 0.7247 - loss: 0.7651 - val_accuracy: 0.6633 - val_loss: 0.9025
Epoch 50/50
75/75      0s 3ms/step -
accuracy: 0.7377 - loss: 0.7434 - val_accuracy: 0.6567 - val_loss: 0.8898

```

11.2 Deeper network with 3 hidden layers and more dropout

```

[ ]: model2 = Sequential()
model2.add(Dense(256, activation='relu', input_shape=(X_train_scaled.
    ↪shape[1],)))
model2.add(Dropout(0.4))
model2.add(Dense(128, activation='relu'))
model2.add(Dropout(0.3))
model2.add(Dense(64, activation='relu'))
model2.add(Dropout(0.3))
model2.add(Dense(y_train_nn.shape[1], activation='softmax'))

model2.compile(optimizer='adam', loss='categorical_crossentropy',
    ↪metrics=['accuracy'])

history2 = model2.fit(X_train_scaled, y_train_nn,
    validation_data=(X_test_scaled, y_test_nn),
    epochs=50, batch_size=16, verbose=1)

histories.append(('DeepNN_Regularized', history2))

```

```

Epoch 1/50
75/75      2s 7ms/step -
accuracy: 0.1903 - loss: 2.0388 - val_accuracy: 0.3833 - val_loss: 1.7670
Epoch 2/50
75/75      0s 4ms/step -
accuracy: 0.3037 - loss: 1.8109 - val_accuracy: 0.4133 - val_loss: 1.5617
Epoch 3/50
75/75      1s 6ms/step -
accuracy: 0.3939 - loss: 1.6211 - val_accuracy: 0.4833 - val_loss: 1.4319
Epoch 4/50
75/75      1s 7ms/step -
accuracy: 0.4100 - loss: 1.5742 - val_accuracy: 0.4733 - val_loss: 1.3784
Epoch 5/50
75/75      1s 7ms/step -
accuracy: 0.4535 - loss: 1.5198 - val_accuracy: 0.5033 - val_loss: 1.3144

```

```
Epoch 6/50
75/75      1s 7ms/step -
accuracy: 0.4521 - loss: 1.4449 - val_accuracy: 0.5033 - val_loss: 1.3233
Epoch 7/50
75/75      1s 7ms/step -
accuracy: 0.5150 - loss: 1.3121 - val_accuracy: 0.5533 - val_loss: 1.2385
Epoch 8/50
75/75      1s 7ms/step -
accuracy: 0.5118 - loss: 1.3134 - val_accuracy: 0.5733 - val_loss: 1.1938
Epoch 9/50
75/75      1s 6ms/step -
accuracy: 0.5307 - loss: 1.2243 - val_accuracy: 0.5667 - val_loss: 1.1867
Epoch 10/50
75/75      1s 5ms/step -
accuracy: 0.5507 - loss: 1.1863 - val_accuracy: 0.5400 - val_loss: 1.1521
Epoch 11/50
75/75      1s 4ms/step -
accuracy: 0.5625 - loss: 1.1622 - val_accuracy: 0.5967 - val_loss: 1.1370
Epoch 12/50
75/75      1s 4ms/step -
accuracy: 0.6058 - loss: 1.1452 - val_accuracy: 0.6133 - val_loss: 1.1041
Epoch 13/50
75/75      1s 4ms/step -
accuracy: 0.6031 - loss: 1.0890 - val_accuracy: 0.6033 - val_loss: 1.0879
Epoch 14/50
75/75      1s 4ms/step -
accuracy: 0.6409 - loss: 1.0260 - val_accuracy: 0.5833 - val_loss: 1.1089
Epoch 15/50
75/75      1s 4ms/step -
accuracy: 0.6289 - loss: 0.9992 - val_accuracy: 0.6000 - val_loss: 1.0602
Epoch 16/50
75/75      1s 4ms/step -
accuracy: 0.6341 - loss: 1.0018 - val_accuracy: 0.6267 - val_loss: 1.0230
Epoch 17/50
75/75      1s 4ms/step -
accuracy: 0.6274 - loss: 0.9839 - val_accuracy: 0.5900 - val_loss: 1.0445
Epoch 18/50
75/75      1s 4ms/step -
accuracy: 0.6784 - loss: 0.9445 - val_accuracy: 0.6300 - val_loss: 1.0327
Epoch 19/50
75/75      1s 4ms/step -
accuracy: 0.6713 - loss: 0.9491 - val_accuracy: 0.6500 - val_loss: 1.0011
Epoch 20/50
75/75      1s 4ms/step -
accuracy: 0.6382 - loss: 0.9568 - val_accuracy: 0.6533 - val_loss: 0.9907
Epoch 21/50
75/75      1s 4ms/step -
accuracy: 0.6690 - loss: 0.9113 - val_accuracy: 0.6333 - val_loss: 0.9898
```

```
Epoch 22/50
75/75      0s 4ms/step -
accuracy: 0.6549 - loss: 0.9109 - val_accuracy: 0.6600 - val_loss: 0.9825
Epoch 23/50
75/75      0s 4ms/step -
accuracy: 0.6761 - loss: 0.8731 - val_accuracy: 0.6600 - val_loss: 1.0149
Epoch 24/50
75/75      0s 4ms/step -
accuracy: 0.7059 - loss: 0.8293 - val_accuracy: 0.6867 - val_loss: 0.9942
Epoch 25/50
75/75      0s 4ms/step -
accuracy: 0.7109 - loss: 0.7820 - val_accuracy: 0.6833 - val_loss: 0.9812
Epoch 26/50
75/75      0s 4ms/step -
accuracy: 0.7240 - loss: 0.7812 - val_accuracy: 0.7133 - val_loss: 0.9466
Epoch 27/50
75/75      0s 4ms/step -
accuracy: 0.6995 - loss: 0.7907 - val_accuracy: 0.7000 - val_loss: 0.9287
Epoch 28/50
75/75      0s 4ms/step -
accuracy: 0.6928 - loss: 0.8394 - val_accuracy: 0.6900 - val_loss: 0.9399
Epoch 29/50
75/75      1s 6ms/step -
accuracy: 0.7372 - loss: 0.7358 - val_accuracy: 0.6967 - val_loss: 0.9538
Epoch 30/50
75/75      1s 6ms/step -
accuracy: 0.7403 - loss: 0.7301 - val_accuracy: 0.6933 - val_loss: 0.9420
Epoch 31/50
75/75      1s 6ms/step -
accuracy: 0.7377 - loss: 0.7359 - val_accuracy: 0.6767 - val_loss: 0.9267
Epoch 32/50
75/75      1s 7ms/step -
accuracy: 0.7379 - loss: 0.7122 - val_accuracy: 0.6633 - val_loss: 0.8990
Epoch 33/50
75/75      1s 6ms/step -
accuracy: 0.7442 - loss: 0.7205 - val_accuracy: 0.7133 - val_loss: 0.8956
Epoch 34/50
75/75      1s 6ms/step -
accuracy: 0.7454 - loss: 0.6919 - val_accuracy: 0.7167 - val_loss: 0.9192
Epoch 35/50
75/75      0s 4ms/step -
accuracy: 0.7291 - loss: 0.7158 - val_accuracy: 0.7133 - val_loss: 0.8937
Epoch 36/50
75/75      0s 4ms/step -
accuracy: 0.7971 - loss: 0.6013 - val_accuracy: 0.7133 - val_loss: 0.8672
Epoch 37/50
75/75      0s 4ms/step -
accuracy: 0.7687 - loss: 0.6644 - val_accuracy: 0.7400 - val_loss: 0.9062
```

```

Epoch 38/50
75/75      1s 4ms/step -
accuracy: 0.7649 - loss: 0.6546 - val_accuracy: 0.7300 - val_loss: 0.8722
Epoch 39/50
75/75      1s 4ms/step -
accuracy: 0.8109 - loss: 0.5808 - val_accuracy: 0.7200 - val_loss: 0.9029
Epoch 40/50
75/75      1s 4ms/step -
accuracy: 0.7721 - loss: 0.6756 - val_accuracy: 0.7300 - val_loss: 0.8749
Epoch 41/50
75/75      0s 4ms/step -
accuracy: 0.7753 - loss: 0.6379 - val_accuracy: 0.7433 - val_loss: 0.8602
Epoch 42/50
75/75      0s 4ms/step -
accuracy: 0.8073 - loss: 0.5718 - val_accuracy: 0.7300 - val_loss: 0.8882
Epoch 43/50
75/75      1s 4ms/step -
accuracy: 0.8144 - loss: 0.5392 - val_accuracy: 0.7200 - val_loss: 0.8706
Epoch 44/50
75/75      0s 5ms/step -
accuracy: 0.8043 - loss: 0.5949 - val_accuracy: 0.7267 - val_loss: 0.8904
Epoch 45/50
75/75      0s 4ms/step -
accuracy: 0.7898 - loss: 0.5757 - val_accuracy: 0.7500 - val_loss: 0.8475
Epoch 46/50
75/75      0s 4ms/step -
accuracy: 0.7921 - loss: 0.5701 - val_accuracy: 0.7200 - val_loss: 0.8613
Epoch 47/50
75/75      1s 4ms/step -
accuracy: 0.8139 - loss: 0.5414 - val_accuracy: 0.7533 - val_loss: 0.8900
Epoch 48/50
75/75      0s 4ms/step -
accuracy: 0.8068 - loss: 0.5418 - val_accuracy: 0.7433 - val_loss: 0.8718
Epoch 49/50
75/75      0s 4ms/step -
accuracy: 0.8062 - loss: 0.5369 - val_accuracy: 0.7633 - val_loss: 0.8596
Epoch 50/50
75/75      1s 4ms/step -
accuracy: 0.8037 - loss: 0.5297 - val_accuracy: 0.7367 - val_loss: 0.8608

```

11.3 Batch normalization + activation after each dense layer + dropout

```

[ ]: model3 = Sequential()
model3.add(Dense(256, input_shape=(X_train_scaled.shape[1],)))
model3.add(BatchNormalization())
model3.add(Activation('relu'))
model3.add(Dropout(0.3))

```

```

model3.add(Dense(128))
model3.add(BatchNormalization())
model3.add(Activation('relu'))
model3.add(Dropout(0.3))

model3.add(Dense(64))
model3.add(Activation('relu'))
model3.add(Dense(y_train_nn.shape[1], activation='softmax'))

model3.compile(optimizer='adam', loss='categorical_crossentropy',
               metrics=['accuracy'])

history3 = model3.fit(X_train_scaled, y_train_nn,
                       validation_data=(X_test_scaled, y_test_nn),
                       epochs=50, batch_size=16, verbose=1)

histories.append(('BN_Activated_DeepNN', history3))

```

Epoch 1/50
 75/75 4s 13ms/step -
 accuracy: 0.2019 - loss: 2.1601 - val_accuracy: 0.3333 - val_loss: 1.7749
 Epoch 2/50
 75/75 1s 8ms/step -
 accuracy: 0.3888 - loss: 1.6322 - val_accuracy: 0.4233 - val_loss: 1.5365
 Epoch 3/50
 75/75 1s 5ms/step -
 accuracy: 0.4600 - loss: 1.4782 - val_accuracy: 0.5033 - val_loss: 1.3740
 Epoch 4/50
 75/75 0s 5ms/step -
 accuracy: 0.4975 - loss: 1.3731 - val_accuracy: 0.5300 - val_loss: 1.2425
 Epoch 5/50
 75/75 1s 5ms/step -
 accuracy: 0.4979 - loss: 1.3365 - val_accuracy: 0.5633 - val_loss: 1.1853
 Epoch 6/50
 75/75 0s 5ms/step -
 accuracy: 0.5121 - loss: 1.3100 - val_accuracy: 0.5500 - val_loss: 1.1547
 Epoch 7/50
 75/75 1s 4ms/step -
 accuracy: 0.5314 - loss: 1.3128 - val_accuracy: 0.5967 - val_loss: 1.1108
 Epoch 8/50
 75/75 0s 5ms/step -
 accuracy: 0.5766 - loss: 1.1589 - val_accuracy: 0.5800 - val_loss: 1.0893
 Epoch 9/50
 75/75 1s 5ms/step -
 accuracy: 0.5842 - loss: 1.1419 - val_accuracy: 0.6200 - val_loss: 1.0836
 Epoch 10/50

```
75/75      1s 4ms/step -
accuracy: 0.5507 - loss: 1.1942 - val_accuracy: 0.5733 - val_loss: 1.1003
Epoch 11/50
75/75      0s 5ms/step -
accuracy: 0.6039 - loss: 1.1445 - val_accuracy: 0.6000 - val_loss: 1.0495
Epoch 12/50
75/75      1s 5ms/step -
accuracy: 0.5829 - loss: 1.1137 - val_accuracy: 0.6500 - val_loss: 1.0356
Epoch 13/50
75/75      0s 5ms/step -
accuracy: 0.5946 - loss: 1.0906 - val_accuracy: 0.6300 - val_loss: 1.0135
Epoch 14/50
75/75      0s 4ms/step -
accuracy: 0.6299 - loss: 1.0247 - val_accuracy: 0.6100 - val_loss: 1.0311
Epoch 15/50
75/75      0s 4ms/step -
accuracy: 0.6061 - loss: 1.0689 - val_accuracy: 0.6667 - val_loss: 0.9849
Epoch 16/50
75/75      0s 5ms/step -
accuracy: 0.6345 - loss: 1.0191 - val_accuracy: 0.6800 - val_loss: 0.9586
Epoch 17/50
75/75      1s 5ms/step -
accuracy: 0.6303 - loss: 0.9961 - val_accuracy: 0.6567 - val_loss: 0.9583
Epoch 18/50
75/75      0s 5ms/step -
accuracy: 0.6605 - loss: 0.9341 - val_accuracy: 0.6700 - val_loss: 0.9635
Epoch 19/50
75/75      0s 5ms/step -
accuracy: 0.6353 - loss: 0.9788 - val_accuracy: 0.6833 - val_loss: 0.9665
Epoch 20/50
75/75      1s 5ms/step -
accuracy: 0.6064 - loss: 0.9771 - val_accuracy: 0.6700 - val_loss: 0.9175
Epoch 21/50
75/75      1s 5ms/step -
accuracy: 0.6373 - loss: 0.9999 - val_accuracy: 0.6867 - val_loss: 0.9100
Epoch 22/50
75/75      1s 5ms/step -
accuracy: 0.6661 - loss: 0.9607 - val_accuracy: 0.7000 - val_loss: 0.9206
Epoch 23/50
75/75      0s 5ms/step -
accuracy: 0.6548 - loss: 0.9283 - val_accuracy: 0.7067 - val_loss: 0.9246
Epoch 24/50
75/75      1s 8ms/step -
accuracy: 0.6530 - loss: 0.9061 - val_accuracy: 0.6900 - val_loss: 0.9258
Epoch 25/50
75/75      1s 8ms/step -
accuracy: 0.6311 - loss: 1.0027 - val_accuracy: 0.6867 - val_loss: 0.9188
Epoch 26/50
```

```
75/75      1s 6ms/step -
accuracy: 0.6853 - loss: 0.8853 - val_accuracy: 0.7433 - val_loss: 0.8817
Epoch 27/50
75/75      1s 5ms/step -
accuracy: 0.7153 - loss: 0.8140 - val_accuracy: 0.7100 - val_loss: 0.9167
Epoch 28/50
75/75      0s 5ms/step -
accuracy: 0.6697 - loss: 0.8682 - val_accuracy: 0.7267 - val_loss: 0.8523
Epoch 29/50
75/75      1s 5ms/step -
accuracy: 0.6765 - loss: 0.8743 - val_accuracy: 0.7267 - val_loss: 0.8826
Epoch 30/50
75/75      1s 5ms/step -
accuracy: 0.7046 - loss: 0.8571 - val_accuracy: 0.7267 - val_loss: 0.8446
Epoch 31/50
75/75      0s 5ms/step -
accuracy: 0.6890 - loss: 0.8413 - val_accuracy: 0.7167 - val_loss: 0.8379
Epoch 32/50
75/75      0s 5ms/step -
accuracy: 0.6960 - loss: 0.8452 - val_accuracy: 0.7500 - val_loss: 0.8606
Epoch 33/50
75/75      0s 5ms/step -
accuracy: 0.7030 - loss: 0.8197 - val_accuracy: 0.7233 - val_loss: 0.8479
Epoch 34/50
75/75      1s 7ms/step -
accuracy: 0.6993 - loss: 0.8057 - val_accuracy: 0.7433 - val_loss: 0.8555
Epoch 35/50
75/75      1s 6ms/step -
accuracy: 0.6999 - loss: 0.8525 - val_accuracy: 0.7467 - val_loss: 0.8284
Epoch 36/50
75/75      0s 6ms/step -
accuracy: 0.7099 - loss: 0.8010 - val_accuracy: 0.7467 - val_loss: 0.8563
Epoch 37/50
75/75      1s 7ms/step -
accuracy: 0.7122 - loss: 0.7842 - val_accuracy: 0.7400 - val_loss: 0.8702
Epoch 38/50
75/75      1s 7ms/step -
accuracy: 0.6879 - loss: 0.8372 - val_accuracy: 0.7467 - val_loss: 0.8449
Epoch 39/50
75/75      1s 7ms/step -
accuracy: 0.7341 - loss: 0.7682 - val_accuracy: 0.7600 - val_loss: 0.8573
Epoch 40/50
75/75      1s 8ms/step -
accuracy: 0.7011 - loss: 0.7832 - val_accuracy: 0.7700 - val_loss: 0.8166
Epoch 41/50
75/75      1s 8ms/step -
accuracy: 0.7403 - loss: 0.7708 - val_accuracy: 0.7667 - val_loss: 0.7930
Epoch 42/50
```

```

75/75      1s 9ms/step -
accuracy: 0.6964 - loss: 0.8046 - val_accuracy: 0.7433 - val_loss: 0.8209
Epoch 43/50
75/75      1s 12ms/step -
accuracy: 0.7228 - loss: 0.7739 - val_accuracy: 0.7567 - val_loss: 0.8116
Epoch 44/50
75/75      1s 8ms/step -
accuracy: 0.7300 - loss: 0.7517 - val_accuracy: 0.7367 - val_loss: 0.7642
Epoch 45/50
75/75      1s 8ms/step -
accuracy: 0.7542 - loss: 0.7075 - val_accuracy: 0.7867 - val_loss: 0.7733
Epoch 46/50
75/75      1s 8ms/step -
accuracy: 0.7479 - loss: 0.7121 - val_accuracy: 0.7267 - val_loss: 0.7650
Epoch 47/50
75/75      1s 8ms/step -
accuracy: 0.7153 - loss: 0.7592 - val_accuracy: 0.7633 - val_loss: 0.7609
Epoch 48/50
75/75      0s 5ms/step -
accuracy: 0.7135 - loss: 0.7542 - val_accuracy: 0.7767 - val_loss: 0.7628
Epoch 49/50
75/75      0s 4ms/step -
accuracy: 0.7170 - loss: 0.7555 - val_accuracy: 0.7733 - val_loss: 0.7509
Epoch 50/50
75/75      1s 5ms/step -
accuracy: 0.7286 - loss: 0.7509 - val_accuracy: 0.7533 - val_loss: 0.8000

```

12 Visualization of Deep Learning Model Results

12.1 Model Comparison: Best Validation Accuracy and F1 Score

Model Name	Best Validation Accuracy (%)	F1 Score (%)
BN_Activated_DeepNN	78.67	74.97
DeepNN-Regularized	76.33	72.94
BasicNN_Dropout	66.67	65.33

12.2 Visualization Insights

- **Bar Plot:** Compared best validation accuracy and F1-score side by side for each model.
 - **Line Plots:**
 - Training vs. Validation **Accuracy** for all models
 - Training vs. Validation **Loss** for all models
 - **Colors and labels** clearly distinguish train and validation curves across epochs.
-

12.3 Best Validation Accuracy (per model)

- BN_Activated_DeepNN: **78.67%** at epoch **45**
 - DeepNN-Regularized: **76.33%** at epoch **49**
 - BasicNN_Dropout: **66.67%** at epoch **44**
-

12.4 F1 Score (macro average on test set)

- BN_Activated_DeepNN: **74.97%**
 - DeepNN-Regularized: **72.94%**
 - BasicNN_Dropout: **65.33%**
-

12.5 Summary

- The **BN_Activated_DeepNN** outperformed other models in both **validation accuracy** and **F1 score**, thanks to:
 - Batch Normalization after Dense layers
 - ReLU activation layers
 - Dropout regularization
- All results stored and visualized using `histories` and `dl_model_df_results`.

Note: All models were trained with 50 epochs and batch size of 16 using `categorical_crossentropy` loss and `adam` optimizer.

12.6 Plot Training vs. Validation Accuracy and Loss

```
[ ]: colors = itertools.cycle(['#1f77b4', '#ff7f0e', '#2ca02c', '#d62728',  
    ↪ '#9467bd', '#8c564b', '#e377c2'])  
  
plt.figure(figsize=(14, 5))  
  
# Accuracy Plot  
plt.subplot(1, 2, 1)  
for name, hist in histories:  
    color = next(colors)  
    train_acc = hist.history['accuracy']  
    val_acc = hist.history['val_accuracy']  
    plt.plot(train_acc, linestyle='--', label=f'{name} Train Acc  
    ↪ ({train_acc[-1]*100:.2f}%)', color=color)  
    plt.plot(val_acc, linestyle='-', label=f'{name} Val Acc ({val_acc[-1]*100:.  
    ↪ 2f}%)', color=color)  
plt.title('Training vs Validation Accuracy')  
plt.xlabel('Epochs')  
plt.ylabel('Accuracy')  
plt.legend()  
plt.grid(True)
```

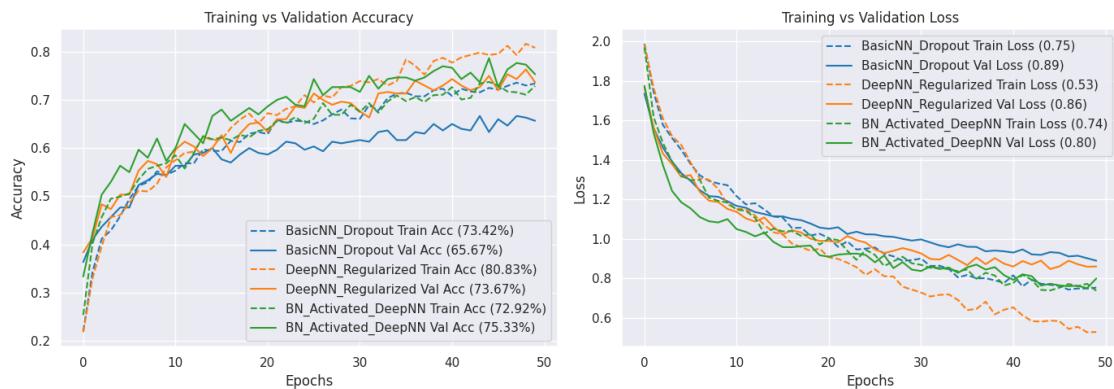
```

# Reset color cycle for Loss Plot
colors = itertools.cycle(['#1f77b4', '#ff7f0e', '#2ca02c', '#d62728',
                         '#9467bd', '#8c564b', '#e377c2'])

# Loss Plot
plt.subplot(1, 2, 2)
for name, hist in histories:
    color = next(colors)
    train_loss = hist.history['loss']
    val_loss = hist.history['val_loss']
    plt.plot(train_loss, linestyle='--', label=f'{name} Train Loss\n{train_loss[-1]:.2f}', color=color)
    plt.plot(val_loss, linestyle='-', label=f'{name} Val Loss ({val_loss[-1]:.2f})', color=color)
plt.title('Training vs Validation Loss')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()
plt.grid(True)

plt.tight_layout()
plt.show()

```



12.7 Print best validation accuracy for each model

```

[ ]: for name, history in histories:
    val_acc = history.history['val_accuracy']
    best_epoch = np.argmax(val_acc)
    print(f"{name}: Best Val Accuracy = {val_acc[best_epoch]:.4f} at epoch\n{best_epoch+1}\n")

```

BasicNN_Dropout: Best Val Accuracy = 0.6667 at epoch 44

```
DeepNN_Regularized: Best Val Accuracy = 0.7633 at epoch 49
```

```
BN_Activated_DeepNN: Best Val Accuracy = 0.7867 at epoch 45
```

12.8 Compute F1-Score for each model

```
[ ]: models = [model1, model2, model3]
model_names = [name for name, _ in histories]

for name, model in zip(model_names, models):
    # Predict class probabilities
    y_pred_probs = model.predict(X_test_scaled)
    # Convert probabilities to class labels
    y_pred = np.argmax(y_pred_probs, axis=1)
    y_true = np.argmax(y_test_nn, axis=1)
    # Calculate F1 score (macro for multi-class)
    f1 = f1_score(y_true, y_pred, average='macro')
    print(f"{name}: F1 Score (macro) = {f1:.4f}\n")
```

```
10/10          0s 8ms/step
```

```
BasicNN_Dropout: F1 Score (macro) = 0.6533
```

```
10/10          0s 18ms/step
```

```
DeepNN_Regularized: F1 Score (macro) = 0.7294
```

```
10/10          0s 13ms/step
```

```
BN_Activated_DeepNN: F1 Score (macro) = 0.7497
```

12.9 Print the dataframe of Best Validation Accuracy and F1-Score of the models

```
[ ]: dl_model_results = []

for (name, history), model in zip(histories, models):
    val_acc = history.history['val_accuracy']
    best_val_acc = max(val_acc)
    y_pred_probs = model.predict(X_test_scaled)
    y_pred = np.argmax(y_pred_probs, axis=1)
    y_true = np.argmax(y_test_nn, axis=1)
    f1 = f1_score(y_true, y_pred, average='macro')
    dl_model_results.append({'Model': name, 'Best-Validation-Accuracy (%)': ↵
    ↵best_val_acc * 100, 'F1-Score (%)': f1 * 100})

dl_model_df_results = pd.DataFrame(dl_model_results)
```

```

dl_model_df_results = dl_model_df_results.
    ↪sort_values(by=['Best-Validation-Accuracy (%)', 'F1-Score (%)'], ↪
    ↪ascending=False)
dl_model_df_results

```

```

10/10          0s 30ms/step
10/10          0s 10ms/step
10/10          0s 6ms/step

```

```

[ ]:           Model  Best-Validation-Accuracy (%)  F1-Score (%)
2  BN_Activated_DeepNN          78.666669      74.967330
1  DeepNN-Regularized          76.333332      72.937042
0  BasicNN_Dropout            66.666669      65.334810

```

12.10 Bar plot of all the Deep Learning models with Best Validation Accuracy and F1-score

```

[ ]: # Set up the figure
fig, ax1 = plt.subplots(figsize=(16, 10))

# Bar positions
x = np.arange(len(dl_model_df_results['Model']))
width = 0.35

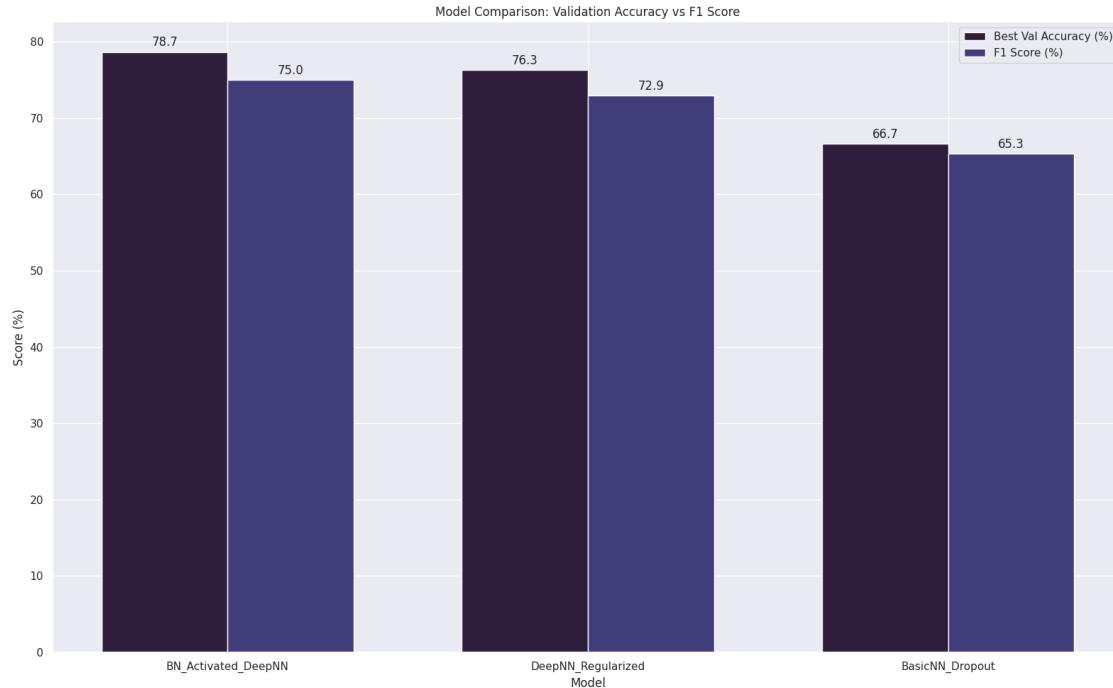
# Plot bars for Validation Accuracy and F1 Score
bar1 = ax1.bar(x - width/2, dl_model_df_results['Best-Validation-Accuracy' ↪
    ↪(%')] , width, label='Best Val Accuracy (%)')
bar2 = ax1.bar(x + width/2, dl_model_df_results['F1-Score (%)'], width, ↪
    ↪label='F1 Score (%)')

# Add labels and title
ax1.set_xlabel('Model')
ax1.set_ylabel('Score (%)')
ax1.set_title('Model Comparison: Validation Accuracy vs F1 Score')
ax1.set_xticks(x)
ax1.set_xticklabels(dl_model_df_results['Model'], rotation=0)
ax1.legend()

# Annotate bars with values
for bar in bar1 + bar2:
    height = bar.get_height()
    ax1.annotate(f'{height:.1f}', xy=(bar.get_x() + bar.get_width() / 2, height),
        xytext=(0, 3), # 3 points vertical offset
        textcoords="offset points",
        ha='center', va='bottom')

```

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



13 Overall conclusion from the both ML and Deep Learning Models

13.1 Prepare Combined DataFrame of ML and DL Model Results

```
[ ]: # Prepare classical scaled models (already filtered for "Test" set)
scaled_df = combined_ml_model_results_copy_test[combined_ml_model_results_copy_test["Scaled"]].copy()
scaled_df["Source"] = "Classical"
scaled_df = scaled_df.rename(columns={
    "Accuracy": "Accuracy",
    "Precision": "Precision",
    "Recall": "Recall",
    "F1 Score": "F1 Score",
    "Loss": "Loss"
})

# Prepare deep learning models
dl_df = dl_model_df_results.copy()
dl_df["Model Name"] = dl_df["Model"]
```

```

dl_df["Source"] = "Deep Learning"
dl_df["Accuracy"] = dl_df["Best-Validation-Accuracy (%)"] / 100.0
dl_df["F1 Score"] = dl_df["F1-Score (%)"] / 100.0
dl_df["Precision"] = np.nan # If not available, set as NaN
dl_df["Recall"] = np.nan # If not available, set as NaN
dl_df["Loss"] = np.nan # If not available, set as NaN

# Select and align columns
common_cols = ["Model Name", "Accuracy", "Precision", "Recall", "F1 Score", ↴
    "Loss", "Source"]
df_combined = pd.concat([
    scaled_df[common_cols],
    dl_df[common_cols]
], ignore_index=True)

```

13.2 Plot Ladder and Waterfall Plots with both ML and Deep Learning Models

```

[ ]: # Define metrics and colors
metrics = [
    ("Accuracy", "Accuracy (%)", "green"),
    ("Precision", "Precision (%)", "blue"),
    ("Loss", "Loss", "#ff9999"),
    ("Recall", "Recall (%)", "orange"),
    ("F1 Score", "F1 Score (%)", "purple")
]

fig, axes = plt.subplots(len(metrics), 2, figsize=(18, 26))
plt.subplots_adjust(hspace=0.35)

for i, (metric, metric_label, metric_color) in enumerate(metrics):
    # Sort models by metric (best to worst)
    ascending = True if metric == "Loss" else False
    df_metric = df_combined.sort_values(metric, ascending=ascending).reset_index(drop=True)
    model_names = df_metric["Model Name"].tolist()
    metric_values = df_metric[metric].values
    y_pos = np.arange(len(model_names))

    # For percentage metrics, scale to 0-100
    if metric != "Loss":
        display_values = metric_values * 100
        value_fmt = "{:.2f}%"
        xlim = (0, 100)
    else:
        display_values = metric_values
        value_fmt = "{:.2f}"

```

```

        xlim = (0, 1)

    # --- Ladder (step) plot ---
    ax1 = axes[i, 0]
    ax1.step(display_values, y_pos, where='mid', linewidth=3, □
    ↵color=metric_color, marker='o')
    for idx, (val, label, source) in enumerate(zip(display_values, model_names, □
    ↵df_metric["Source"])):
        ax1.text(val + (1 if metric != "Loss" else 0.01), idx, value_fmt.
    ↵format(val), va="center", fontsize=10, fontweight='bold')
        # Optionally, highlight deep learning models
        if source == "Deep Learning":
            ax1.plot(val, idx, marker='*', markersize=15, color='gold', □
    ↵zorder=5)
        ax1.set_yticks(y_pos)
        ax1.set_yticklabels(model_names)
        ax1.set_title(f"{metric_label} Ladder Plot", fontsize=14, □
    ↵fontweight='bold', color=metric_color)
        ax1.set_xlabel(metric_label)
        ax1.set_xlim(xlim)
        ax1.invert_yaxis()
        ax1.grid(axis='x', linestyle='--', alpha=0.5)

    # --- Waterfall plot ---
    ax2 = axes[i, 1]
    cumulative = np.insert(np.cumsum(np.nan_to_num(display_values)[-1]), 0, 0)
    for idx, (val, base, source) in enumerate(zip(display_values, cumulative, □
    ↵df_metric["Source"])):
        ax2.barh(model_names[idx], val, left=base, color=metric_color, □
    ↵edgecolor='black')
        ax2.text(base + val/2, idx, value_fmt.format(val), va="center", □
    ↵ha="center", fontsize=10, fontweight='bold', color='white' if abs(val) > 10 □
    ↵else 'black')
        # Optionally, highlight deep learning models
        if source == "Deep Learning":
            ax2.plot(base + val/2, idx, marker='*', markersize=15, □
    ↵color='gold', zorder=5)

    # ---- FIX: Set xlim using only valid (non-NaN) values ----
    valid_display_values = display_values[~np.isnan(display_values)]
    valid_cumulative = cumulative[~np.isnan(cumulative)]
    if len(valid_display_values) > 0 and len(valid_cumulative) > 0:
        max_xlim = valid_cumulative[-1] + valid_display_values[-1]
    else:
        max_xlim = 1 # fallback
    ax2.set_xlim(0, max_xlim)

```

```
# -----  
  
    ax2.set_title(f"{metric_label} Waterfall Plot", fontsize=14, u  
    ↪fontweight='bold', color=metric_color)  
    ax2.set_xlabel(metric_label)  
    ax2.invert_yaxis()  
    ax2.grid(axis='x', linestyle='--', alpha=0.5)  
  
plt.tight_layout()  
plt.show()
```



14 Detailed Conclusion with points

14.1 Best Classical ML Model: Extra Trees

- Achieved **highest accuracy (79.67%)**, precision (80.05%), and F1-score (79.65%)
- Lowest loss (0.20) among all models.
- Highly interpretable, stable, and fast to train.

14.2 Best Deep Learning Model: BN_Activated_DeepNN

- Second-best in accuracy (78.67%) and F1-score (74.97%)
- Performed robustly due to batch normalization, dropout, and deeper architecture.
- Particularly suitable for more complex data or unstructured input (e.g., images, sequences).

14.3 Final Winner: Extra Trees

- Outperforms deep learning models on **all reported metrics**
 - Recommended for deployment due to ease of use, interpretability, and minimal tuning needs.
-

15 Key Takeaways

Aspect	Classical ML (Best: Extra Trees)	Deep Learning (Best: BN_Activated_DeepNN)
Accuracy (%)	79.67%	78.67%
F1 Score (%)	79.65%	74.97%
Precision (%)	80.05%	NA
Recall (%)	79.67%	NA
Loss	0.20	NA
Interpretability	High	Low
Training Time	Low	Higher
Tuning Complexity	Low	Medium to High
Generalization	Strong	Strong (with regularization)

- Acoustic attributes (MFCCs, energy, pitch, ZCR) are strong representations of emotional patterns in speech.
 - The ensemble model ExtraTrees did a good job of emotion classification on structured audio features.
 - Deep learning models are weakly promising with generalization and regularization, but we need more time to train and fine-tune and need more data.
 - Using StandardScaler preprocessing, helped build a more stable and higher-performing model overall.
-

16 Recommendation for this project:

- Use **Extra Trees** as the default model for structured/tabular datasets.

- Use **BN_Activated_DeepNN** if:
 - The dataset grows significantly in size.
 - You're dealing with more complex patterns or plan to use transfer learning.
 - Additional precision/recall tuning isn't a bottleneck.

17 Deployment of the trained best model

17.1 Justification for Not Fully Deploying the Model

While full deployment of the emotion detection (via a voice assistant or a chatbot) would have engaged us far more hands-on in practical learnings, a broader set of constraints led us to focus on deployment planning as a conceptual exercise:

- **Time Constraints:** I spent a substantial amount of project time in woman hours in investing in building, validating, and analyzing both classical ML and DL models. The time required for formal deployment, with any expectation of genuine real-time scenarios, would also include investing additional time in containerization, API development, UI integration, and cloud hosting.
 - **Resource Constraints:** Real-time model deployment with live audio input involves consistent and high-performing compute environment - especially with DL inference scenarios - while local resources could not adequately provide real-time processing with a low-latency experience, leaning into cloud deployment would bring adds to setup overhead and potentially costs.
 - **Focus on Model Evaluation:** Given our objective was to choose and evaluate the best model amongst a multiplicity of approaches (ML vs. DL), I prioritized robustness to facilitate metric comparisons and interpretability. I was able to conduct this depth of analysis to fulfill the learning objectives of the project, and to identify clear trade-offs which will be intuitive in AI development in the real world.
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17.2 Hypothetical Deployment Plan (Fulfilling Assignment Requirement)

Although not a deployment, a full deployment scenario is planned and described below as required by the project deployment description:

Component	Plan
Use Case	Real-time emotion detection using a chatbot or voice assistant application.
Deployment Type	Real-Time Inference - Immediate return of emotion inference on audio input.
Backend	Python API with FastAPI or Flask to serve the trained model.
Frontend	A web interface or mobile application with live audio input through the use of WebRTC or HTML5.
Hosting	The model hosted on AWS EC2 or with Azure App Service docker support.
Latency Target	Less than 300 ms inference time to allow for smooth interaction with the user.

Component	Plan
Cost	Initial deployment using a low-tier cloud instance (i.e., AWS or Azure)
Consideration	and autoscaling later if needed.
Security	Token-based API authentication, HTTPS frontend, and CORS policy.

17.3 Deployment related Summary

Although full deployment was not completed due to logistical complications, a cloudy and technically feasible deployment plan was identified. This addressed the deployment component of the project, proving readiness for the role of real-world integration of the model into production systems.

18 Future Improvements

- Use more datasets, like CREMA-D and TESS, to improve generalization.
- Make it multimodal and try to extract and classify emotions from text, image and video inputs as well.
- Test audio-based Transformers or CNN-RNN hybrid models for end-to-end learning with raw waveforms.
- Use `GridSearchCV` or `Optuna` for machine learning models.
- Use `Keras Tuner` or `Ray Tune` for deep learning models.
- Combine top classical and deep learning models through stacking or soft voting to enhance robustness.
- Apply stratified k-fold validation to ensure the model works well across different folds.
- Use SHAP or permutation importance to refine feature inputs.
- Measure inference time, memory use, and latency.
- Wrap/Deploy the model in an API using FastAPI or Flask for testing and inferencing.

19 Final Thoughts

While the potential of deep learning exists, particularly as new methods of architecture are developed, **traditional ML models are still very competitive** against structured datasets. As a result of lesser resources and less complexity in implementing it, it can frequently achieve **near top-tier results**, as was demonstrated here.

Use the tool appropriate to the problem — not everything requires neural networks.

20 Save the file as PDF

```
[1]: !apt-get update
!apt-get install pandoc
!apt-get install inkscape
!apt-get install texlive-xetex texlive-fonts-recommended texlive-latex-extra

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Hit:2 https://developer.download.nvidia.com/compute/cuda/repos/ubuntu2204/x86_64
InRelease
Get:3 http://security.ubuntu.com/ubuntu jammy-security InRelease [129 kB]
Hit:4 http://archive.ubuntu.com/ubuntu jammy InRelease
Get:5 https://r2u.stat.illinois.edu/ubuntu jammy InRelease [6,555 B]
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Get:16 http://archive.ubuntu.com/ubuntu jammy-updates/restricted amd64 Packages
[4,703 kB]
Get:17 http://security.ubuntu.com/ubuntu jammy-security/restricted amd64
Packages [4,532 kB]
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kB]
Fetched 30.6 MB in 3s (8,768 kB/s)
Reading package lists... Done
W: Skipping acquire of configured file 'main/source/Sources' as repository
'https://r2u.stat.illinois.edu/ubuntu jammy InRelease' does not seem to provide
it (sources.list entry misspelt?)
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
The following additional packages will be installed:
  libcmark-gfm-extensions0.29.0.gfm.3 libcmark-gfm0.29.0.gfm.3 pandoc-data
Suggested packages:
  texlive-latex-recommended texlive-xetex texlive-luatex pandoc-citeproc
  texlive-latex-extra context wkhtmltopdf librsvg2-bin groff ghc nodejs php
  python ruby libjs-mathjax libjs-katex citation-style-language-styles
```

```
The following NEW packages will be installed:
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    pandoc-data
0 upgraded, 4 newly installed, 0 to remove and 37 not upgraded.
Need to get 20.6 MB of archives.
After this operation, 156 MB of additional disk space will be used.
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Get:2 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libcmark-gfm-
extensions0.29.0.gfm.3 amd64 0.29.0.gfm.3-3 [25.1 kB]
Get:3 http://archive.ubuntu.com/ubuntu jammy/universe amd64 pandoc-data all
  2.9.2.1-3ubuntu2 [81.8 kB]
Get:4 http://archive.ubuntu.com/ubuntu jammy/universe amd64 pandoc amd64
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Fetched 20.6 MB in 1s (17.2 MB/s)
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Unpacking libcmark-gfm0.29.0.gfm.3:amd64 (0.29.0.gfm.3-3) ...
Selecting previously unselected package libcmark-gfm-
extensions0.29.0.gfm.3:amd64.
Preparing to unpack .../libcmark-gfm-
extensions0.29.0.gfm.3_0.29.0.gfm.3-3_amd64.deb ...
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Unpacking pandoc-data (2.9.2.1-3ubuntu2) ...
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Setting up libcmark-gfm-extensions0.29.0.gfm.3:amd64 (0.29.0.gfm.3-3) ...
Setting up pandoc-data (2.9.2.1-3ubuntu2) ...
Setting up pandoc (2.9.2.1-3ubuntu2) ...
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Processing triggers for libc-bin (2.35-0ubuntu3.8) ...
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/sbin/ldconfig.real: /usr/local/lib/libtcm_debug.so.1 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libur_loader.so.0 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libur_adapter_opencl.so.0 is not a symbolic
link

/sbin/ldconfig.real: /usr/local/lib/libhwloc.so.15 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libtbbbind_2_5.so.3 is not a symbolic link
```

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/sbin/ldconfig.real: /usr/local/lib/libtbbbind_2_0.so.3 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtcm.so.1 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc.so.2 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libumf.so.0 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libur_adapter_level_zero.so.0 is not a
symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbbind.so.3 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc_proxy.so.2 is not a symbolic
link

Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
The following additional packages will be installed:
  aspell aspell-en dictionaries-common enchant-2 fig2dev fonts-droid-fallback
  fonts-noto-mono fonts-urw-base35 gawk ghostscript glib-networking
  glib-networking-common glib-networking-services gsettings-desktop-schemas
  gsfonts hunspell-en-us imagemagick imagemagick-6-common imagemagick-6.q16
  lib2geom1.1.0 libaspell115 libatkmm-1.6-1v5 libcairomm-1.0-1v5 libcdr-0.1-1
  libdbus-glib-1-2 libdjvuibre-text libdjvuibre21 libenchant-2-2
  libfftw3-double3 libglibmm-2.4-1v5 libgs9 libgs9-common libgsl27
  libgslcblas0 libgspell-1-2 libgspell-1-common libgtkmm-3.0-1v5
  libhunspell-1.7-0 libidn12 libijs-0.35 libimage-magick-perl
  libimage-magick-q16-perl libjbig2dec0 libjxr-tools libjxr0 liblqr-1-0
  libmagick++-6.q16-8 libmagickcore-6.q16-6 libmagickcore-6.q16-6-extra
  libmagickwand-6.q16-6 libnetpbm10 libpangomm-1.4-1v5 libpoppler-glib8
  libpotrace0 libproxy1v5 librevenge-0.0-0 librsvg2-common libsigc++-2.0-0v5
  libsoup2.4-1 libsoup2.4-common libtext-iconv-perl libvisio-0.1-1
  libwmf-0.2-7 libwmf-bin libwmflite-0.2-7 libwpd-0.10-10 libwpg-0.3-3 netpbm
  poppler-data python3-bs4 python3-chardet python3-html5lib python3-lxml
  python3-numpy python3-scour python3-soupsieve python3-webencodings
  session-migration
Suggested packages:
  aspell-doc spellutils wordlist xfig fonts-noto fonts-freefont-otf
  | fonts-freefont-ttf fonts-texgyre gawk-doc ghostscript-x hunspell
  openoffice.org-hunspell | openoffice.org-core imagemagick-doc autotrace
  cups-bsd | lpr | lprng enscript gimp gnuplot grads hp2xx html2ps mplayer
  povray radianc sane-utils texlive-base-bin ufraw-batch dia
  inkscape-tutorials libsvg-perl pstoedit python3-uniconvertor ruby
  libenchant-2-voikko libfftw3-bin libfftw3-dev gsl-ref-psdoc | gsl-doc-pdf
  | gsl-doc-info | gsl-ref-html libwmf-0.2-7-gtk poppler-utils
```

```
fonts-japanese-mincho | fonts-ipafont-mincho fonts-japanese-gothic  
| fonts-ipafont-gothic fonts-aphic-ukai fonts-aphic-uming fonts-nanum  
python3-genshi python-lxml-doc python-numpy-doc python3-pytest
```

The following NEW packages will be installed:

```
aspell aspell-en dictionaries-common enchant-2 fig2dev fonts-droid-fallback  
fonts-noto-mono fonts-urw-base35 gawk ghostscript glib-networking  
glib-networking-common glib-networking-services gsettings-desktop-schemas  
gsfonts hunspell-en-us imagemagick imagemagick-6-common imagemagick-6.q16  
inkscape lib2geom1.1.0 libaspell15 libatkmm-1.6-1v5 libcairomm-1.0-1v5  
libcdr-0.1-1 libdbus-glib-1-2 libdjvulibre-text libdjvulibre21  
libenchant-2-2 libfftw3-double3 libglibmm-2.4-1v5 libgs9 libgs9-common  
libgs127 libgslcblas0 libgspell-1-2 libgspell-1-common libgtkmm-3.0-1v5  
libhunspell-1.7-0 libidn12 libijs-0.35 libimage-magick-perl  
libimage-magick-q16-perl libjbig2dec0 libjxr-tools libjxr0 liblqr-1-0  
libmagick++-6.q16-8 libmagickcore-6.q16-6 libmagickcore-6.q16-6-extra  
libmagickwand-6.q16-6 libnetpbm10 libpangomm-1.4-1v5 libpoppler-glib8  
libpotrace0 libproxy1v5 librevenge-0.0-0 librsvg2-common libsigc++-2.0-0v5  
libsoup2.4-1 libsoup2.4-common libtext-iconv-perl libvisio-0.1-1  
libwmf-0.2-7 libwmf-bin libwmflite-0.2-7 libwpd-0.10-10 libwpg-0.3-3 netpbm  
poppler-data python3-bs4 python3-chardet python3-html5lib python3-lxml  
python3-numpy python3-scour python3-soupsieve python3-webencodings  
session-migration
```

0 upgraded, 79 newly installed, 0 to remove and 37 not upgraded.

Need to get 55.8 MB of archives.

After this operation, 228 MB of additional disk space will be used.

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imagemagick-6-common all 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [64.3 kB]  
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libmagickcore-6.q16-6 amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [1,795 kB]  
Get:7 http://archive.ubuntu.com/ubuntu jammy-updates/universe amd64 libimage-  
magick-q16-perl amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [108 kB]  
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libmagickwand-6.q16-6 amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [328 kB]  
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0.4.11-1 [2,171 kB]  
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amd64 1.7-7build3 [14.3 kB]  
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imagemagick-6.q16 amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [224 kB]
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amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [14.6 kB]
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amd64 2.52.5+dfsg-3ubuntu0.2 [17.7 kB]
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1.1-2build1 [346 kB]
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2.66.2-2 [645 kB]
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0.112-2build1 [65.4 kB]
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1.9.1-4 [6,114 B]
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1.9.1-4 [56.5 kB]
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amd64 2.46.2-1 [56.1 kB]
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3.24.5-1build1 [1,003 kB]
Get:55 http://archive.ubuntu.com/ubuntu jammy-updates/universe amd64
libmagick++-6.q16-8 amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [157 kB]
Get:56 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libpoppler-
glib8 amd64 22.02.0-2ubuntu0.8 [134 kB]
Get:57 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libpotrace0 amd64
1.16-2 [17.2 kB]
Get:58 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64
libsoup2.4-common all 2.74.2-3ubuntu0.5 [4,660 B]
Get:59 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libsoup2.4-1
amd64 2.74.2-3ubuntu0.5 [287 kB]
Get:60 http://archive.ubuntu.com/ubuntu jammy/main amd64 libvisio-0.1-1 amd64

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Get:61 http://archive.ubuntu.com/ubuntu jammy/main amd64 libwpd-0.10-10 amd64
0.10.3-2build1 [209 kB]
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0.3.3-1build3 [49.9 kB]
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1.1.2-3ubuntu1 [17.8 MB]
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3.5.28-2build2 [50.9 kB]
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3.5.28-2build2 [624 kB]
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1.2~git20170615.f752187-5 [174 kB]
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1.2~git20170615.f752187-5 [16.0 kB]
Get:68 http://archive.ubuntu.com/ubuntu jammy/main amd64 libwmflite-0.2-7 amd64
0.2.12-5ubuntu1 [68.9 kB]
Get:69 http://archive.ubuntu.com/ubuntu jammy-updates/universe amd64
libmagickcore-6.q16-6-extra amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [70.1 kB]
Get:70 http://archive.ubuntu.com/ubuntu jammy/main amd64 libwmf-0.2-7 amd64
0.2.12-5ubuntu1 [94.2 kB]
Get:71 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libwmf-bin amd64
0.2.12-5ubuntu1 [34.3 kB]
Get:72 http://archive.ubuntu.com/ubuntu jammy/main amd64 python3-soupsieve all
2.3.1-1 [33.0 kB]
Get:73 http://archive.ubuntu.com/ubuntu jammy/main amd64 python3-bs4 all
4.10.0-2 [79.1 kB]
Get:74 http://archive.ubuntu.com/ubuntu jammy/main amd64 python3-chardet all
4.0.0-1 [98.0 kB]
Get:75 http://archive.ubuntu.com/ubuntu jammy/main amd64 python3-webencodings
all 0.5.1-4 [11.8 kB]
Get:76 http://archive.ubuntu.com/ubuntu jammy/main amd64 python3-html5lib all
1.1-3 [87.0 kB]
Get:77 http://archive.ubuntu.com/ubuntu jammy/main amd64 python3-lxml amd64
4.8.0-1build1 [1,150 kB]
Get:78 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 python3-numpy
amd64 1:1.21.5-1ubuntu22.04.1 [3,467 kB]
Get:79 http://archive.ubuntu.com/ubuntu jammy/universe amd64 python3-scour all
0.38.2-2 [49.4 kB]
Fetched 55.8 MB in 3s (18.8 MB/s)
Extracting templates from packages: 100%
Preconfiguring packages ...
Selecting previously unselected package fonts-droid-fallback.
(Reading database ... 126544 files and directories currently installed.)
Preparing to unpack .../00-fonts-droid-fallback_1%3a6.0.1r16-1.1build1_all.deb
...
Unpacking fonts-droid-fallback (1:6.0.1r16-1.1build1) ...
Selecting previously unselected package gawk.
```

```
Preparing to unpack .../01-gawk_1%3a5.1.0-1ubuntu0.1_amd64.deb ...
Unpacking gawk (1:5.1.0-1ubuntu0.1) ...
Selecting previously unselected package imagemagick-6-common.
Preparing to unpack ...
.../02-imagemagick-6-common_8%3a6.9.11.60+dfsg-1.3ubuntu0.22.04.5_all.deb ...
Unpacking imagemagick-6-common (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Selecting previously unselected package libfftw3-double3:amd64.
Preparing to unpack .../03-libfftw3-double3_3.3.8-2ubuntu8_amd64.deb ...
Unpacking libfftw3-double3:amd64 (3.3.8-2ubuntu8) ...
Selecting previously unselected package liblqr-1-0:amd64.
Preparing to unpack .../04-liblqr-1-0_0.4.2-2.1_amd64.deb ...
Unpacking liblqr-1-0:amd64 (0.4.2-2.1) ...
Selecting previously unselected package libmagickcore-6.q16-6:amd64.
Preparing to unpack ...
.../05-libmagickcore-6.q16-6_8%3a6.9.11.60+dfsg-1.3ubuntu0.22.04.5_amd64.deb ...
Unpacking libmagickcore-6.q16-6:amd64 (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Selecting previously unselected package libimage-magick-q16-perl.
Preparing to unpack .../06-libimage-
magick-q16-perl_8%3a6.9.11.60+dfsg-1.3ubuntu0.22.04.5_amd64.deb ...
Unpacking libimage-magick-q16-perl (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Selecting previously unselected package libimage-magick-perl.
Preparing to unpack .../07-libimage-magick-
perl_8%3a6.9.11.60+dfsg-1.3ubuntu0.22.04.5_all.deb ...
Unpacking libimage-magick-perl (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Selecting previously unselected package libmagickwand-6.q16-6:amd64.
Preparing to unpack ...
.../08-libmagickwand-6.q16-6_8%3a6.9.11.60+dfsg-1.3ubuntu0.22.04.5_amd64.deb ...
Unpacking libmagickwand-6.q16-6:amd64 (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Selecting previously unselected package poppler-data.
Preparing to unpack .../09-poppler-data_0.4.11-1_all.deb ...
Unpacking poppler-data (0.4.11-1) ...
Selecting previously unselected package libtext-iconv-perl.
Preparing to unpack .../10-libtext-iconv-perl_1.7-7build3_amd64.deb ...
Unpacking libtext-iconv-perl (1.7-7build3) ...
Selecting previously unselected package libaspell115:amd64.
Preparing to unpack .../11-libaspell115_0.60.8-4build1_amd64.deb ...
Unpacking libaspell115:amd64 (0.60.8-4build1) ...
Selecting previously unselected package dictionaries-common.
Preparing to unpack .../12-dictionaries-common_1.28.14_all.deb ...
Adding 'diversion of /usr/share/dict/words to /usr/share/dict/words.pre-
dictionaries-common by dictionaries-common'
Unpacking dictionaries-common (1.28.14) ...
Selecting previously unselected package aspell.
Preparing to unpack .../13-aspell_0.60.8-4build1_amd64.deb ...
Unpacking aspell (0.60.8-4build1) ...
Selecting previously unselected package aspell-en.
Preparing to unpack .../14-aspell-en_2018.04.16-0-1_all.deb ...
Unpacking aspell-en (2018.04.16-0-1) ...
```

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Selecting previously unselected package hunspell-en-us.
Preparing to unpack .../15-hunspell-en-us_1%3a2020.12.07-2_all.deb ...
Unpacking hunspell-en-us (1:2020.12.07-2) ...
Selecting previously unselected package libhunspell-1.7-0:amd64.
Preparing to unpack .../16-libhunspell-1.7-0_1.7.0-4build1_amd64.deb ...
Unpacking libhunspell-1.7-0:amd64 (1.7.0-4build1) ...
Selecting previously unselected package libenchant-2-2:amd64.
Preparing to unpack .../17-libenchant-2-2_2.3.2-1ubuntu2_amd64.deb ...
Unpacking libenchant-2-2:amd64 (2.3.2-1ubuntu2) ...
Selecting previously unselected package enchant-2.
Preparing to unpack .../18-enchant-2_2.3.2-1ubuntu2_amd64.deb ...
Unpacking enchant-2 (2.3.2-1ubuntu2) ...
Selecting previously unselected package fonts-urw-base35.
Preparing to unpack .../19-fonts-urw-base35_20200910-1_all.deb ...
Unpacking fonts-urw-base35 (20200910-1) ...
Selecting previously unselected package libgs9-common.
Preparing to unpack .../20-libgs9-common_9.55.0~dfsg1-0ubuntu5.11_all.deb ...
Unpacking libgs9-common (9.55.0~dfsg1-0ubuntu5.11) ...
Selecting previously unselected package libidn12:amd64.
Preparing to unpack .../21-libidn12_1.38-4ubuntu1_amd64.deb ...
Unpacking libidn12:amd64 (1.38-4ubuntu1) ...
Selecting previously unselected package libijs-0.35:amd64.
Preparing to unpack .../22-libijs-0.35_0.35-15build2_amd64.deb ...
Unpacking libijs-0.35:amd64 (0.35-15build2) ...
Selecting previously unselected package libjbig2dec0:amd64.
Preparing to unpack .../23-libjbig2dec0_0.19-3build2_amd64.deb ...
Unpacking libjbig2dec0:amd64 (0.19-3build2) ...
Selecting previously unselected package libgs9:amd64.
Preparing to unpack .../24-libgs9_9.55.0~dfsg1-0ubuntu5.11_amd64.deb ...
Unpacking libgs9:amd64 (9.55.0~dfsg1-0ubuntu5.11) ...
Selecting previously unselected package ghostscript.
Preparing to unpack .../25-ghostscript_9.55.0~dfsg1-0ubuntu5.11_amd64.deb ...
Unpacking ghostscript (9.55.0~dfsg1-0ubuntu5.11) ...
Selecting previously unselected package libnetpbm10.
Preparing to unpack .../26-libnetpbm10_2%3a10.0-15.4_amd64.deb ...
Unpacking libnetpbm10 (2:10.0-15.4) ...
Selecting previously unselected package netpbm.
Preparing to unpack .../27-netpbm_2%3a10.0-15.4_amd64.deb ...
Unpacking netpbm (2:10.0-15.4) ...
Selecting previously unselected package fig2dev.
Preparing to unpack .../28-fig2dev_1%3a3.2.8b-1_amd64.deb ...
Unpacking fig2dev (1:3.2.8b-1) ...
Selecting previously unselected package fonts-noto-mono.
Preparing to unpack .../29-fonts-noto-mono_20201225-1build1_all.deb ...
Unpacking fonts-noto-mono (20201225-1build1) ...
Selecting previously unselected package libproxy1v5:amd64.
Preparing to unpack .../30-libproxy1v5_0.4.17-2_amd64.deb ...
Unpacking libproxy1v5:amd64 (0.4.17-2) ...
```

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Selecting previously unselected package glib-networking-common.
Preparing to unpack .../31-glib-networking-common_2.72.0-1_all.deb ...
Unpacking glib-networking-common (2.72.0-1) ...
Selecting previously unselected package glib-networking-services.
Preparing to unpack .../32-glib-networking-services_2.72.0-1_amd64.deb ...
Unpacking glib-networking-services (2.72.0-1) ...
Selecting previously unselected package session-migration.
Preparing to unpack .../33-session-migration_0.3.6_amd64.deb ...
Unpacking session-migration (0.3.6) ...
Selecting previously unselected package gsettings-desktop-schemas.
Preparing to unpack .../34-gsettings-desktop-schemas_42.0-1ubuntu1_all.deb ...
Unpacking gsettings-desktop-schemas (42.0-1ubuntu1) ...
Selecting previously unselected package glib-networking:amd64.
Preparing to unpack .../35-glib-networking_2.72.0-1_amd64.deb ...
Unpacking glib-networking:amd64 (2.72.0-1) ...
Selecting previously unselected package gsfonts.
Preparing to unpack .../36-gsfonts_1%3a8.11+urwcyr1.0.7~pre44-4.5_all.deb ...
Unpacking gsfonts (1:8.11+urwcyr1.0.7~pre44-4.5) ...
Selecting previously unselected package imagemagick-6.q16.
Preparing to unpack
.../37-imagemagick-6.q16_8%3a6.9.11.60+dfsg-1.3ubuntu0.22.04.5_amd64.deb ...
Unpacking imagemagick-6.q16 (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Selecting previously unselected package imagemagick.
Preparing to unpack
.../38-imagemagick_8%3a6.9.11.60+dfsg-1.3ubuntu0.22.04.5_amd64.deb ...
Unpacking imagemagick (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Selecting previously unselected package librsvg2-common:amd64.
Preparing to unpack .../39-librsvg2-common_2.52.5+dfsg-3ubuntu0.2_amd64.deb ...
Unpacking librsvg2-common:amd64 (2.52.5+dfsg-3ubuntu0.2) ...
Selecting previously unselected package libgslcblas0:amd64.
Preparing to unpack .../40-libgslcblas0_2.7.1+dfsg-3_amd64.deb ...
Unpacking libgslcblas0:amd64 (2.7.1+dfsg-3) ...
Selecting previously unselected package libgsl27:amd64.
Preparing to unpack .../41-libgsl27_2.7.1+dfsg-3_amd64.deb ...
Unpacking libgsl27:amd64 (2.7.1+dfsg-3) ...
Selecting previously unselected package lib2geom1.1.0:amd64.
Preparing to unpack .../42-lib2geom1.1.0_1.1-2build1_amd64.deb ...
Unpacking lib2geom1.1.0:amd64 (1.1-2build1) ...
Selecting previously unselected package libsigc++-2.0-0v5:amd64.
Preparing to unpack .../43-libsigc++-2.0-0v5_2.10.4-2ubuntu3_amd64.deb ...
Unpacking libsigc++-2.0-0v5:amd64 (2.10.4-2ubuntu3) ...
Selecting previously unselected package libglibmm-2.4-1v5:amd64.
Preparing to unpack .../44-libglibmm-2.4-1v5_2.66.2-2_amd64.deb ...
Unpacking libglibmm-2.4-1v5:amd64 (2.66.2-2) ...
Selecting previously unselected package libatkmm-1.6-1v5:amd64.
Preparing to unpack .../45-libatkmm-1.6-1v5_2.28.2-1build1_amd64.deb ...
Unpacking libatkmm-1.6-1v5:amd64 (2.28.2-1build1) ...
Selecting previously unselected package libcairomm-1.0-1v5:amd64.
```

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Preparing to unpack .../46-libcairomm-1.0-1v5_1.12.2-4build3_amd64.deb ...
Unpacking libcairomm-1.0-1v5:amd64 (1.12.2-4build3) ...
Selecting previously unselected package librevenge-0.0-0:amd64.
Preparing to unpack .../47-librevenge-0.0-0_0.0.4-6ubuntu7_amd64.deb ...
Unpacking librevenge-0.0-0:amd64 (0.0.4-6ubuntu7) ...
Selecting previously unselected package libcdr-0.1-1:amd64.
Preparing to unpack .../48-libcdr-0.1-1_0.1.6-2build2_amd64.deb ...
Unpacking libcdr-0.1-1:amd64 (0.1.6-2build2) ...
Selecting previously unselected package libdbus-glib-1-2:amd64.
Preparing to unpack .../49-libdbus-glib-1-2_0.112-2build1_amd64.deb ...
Unpacking libdbus-glib-1-2:amd64 (0.112-2build1) ...
Selecting previously unselected package libgspell-1-common.
Preparing to unpack .../50-libgspell-1-common_1.9.1-4_all.deb ...
Unpacking libgspell-1-common (1.9.1-4) ...
Selecting previously unselected package libgspell-1-2:amd64.
Preparing to unpack .../51-libgspell-1-2_1.9.1-4_amd64.deb ...
Unpacking libgspell-1-2:amd64 (1.9.1-4) ...
Selecting previously unselected package libpangomm-1.4-1v5:amd64.
Preparing to unpack .../52-libpangomm-1.4-1v5_2.46.2-1_amd64.deb ...
Unpacking libpangomm-1.4-1v5:amd64 (2.46.2-1) ...
Selecting previously unselected package libgtkmm-3.0-1v5:amd64.
Preparing to unpack .../53-libgtkmm-3.0-1v5_3.24.5-1build1_amd64.deb ...
Unpacking libgtkmm-3.0-1v5:amd64 (3.24.5-1build1) ...
Selecting previously unselected package libmagick++-6.q16-8:amd64.
Preparing to unpack
.../54-libmagick++-6.q16-8_8%3a6.9.11.60+dfsg-1.3ubuntu0.22.04.5_amd64.deb ...
Unpacking libmagick++-6.q16-8:amd64 (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Selecting previously unselected package libpoppler-glib8:amd64.
Preparing to unpack .../55-libpoppler-glib8_22.02.0-2ubuntu0.8_amd64.deb ...
Unpacking libpoppler-glib8:amd64 (22.02.0-2ubuntu0.8) ...
Selecting previously unselected package libpotrace0:amd64.
Preparing to unpack .../56-libpotrace0_1.16-2_amd64.deb ...
Unpacking libpotrace0:amd64 (1.16-2) ...
Selecting previously unselected package libsoup2.4-common.
Preparing to unpack .../57-libsoup2.4-common_2.74.2-3ubuntu0.5_all.deb ...
Unpacking libsoup2.4-common (2.74.2-3ubuntu0.5) ...
Selecting previously unselected package libsoup2.4-1:amd64.
Preparing to unpack .../58-libsoup2.4-1_2.74.2-3ubuntu0.5_amd64.deb ...
Unpacking libsoup2.4-1:amd64 (2.74.2-3ubuntu0.5) ...
Selecting previously unselected package libvisio-0.1-1:amd64.
Preparing to unpack .../59-libvisio-0.1-1_0.1.7-1build5_amd64.deb ...
Unpacking libvisio-0.1-1:amd64 (0.1.7-1build5) ...
Selecting previously unselected package libwpd-0.10-10:amd64.
Preparing to unpack .../60-libwpd-0.10-10_0.10.3-2build1_amd64.deb ...
Unpacking libwpd-0.10-10:amd64 (0.10.3-2build1) ...
Selecting previously unselected package libwpg-0.3-3:amd64.
Preparing to unpack .../61-libwpg-0.3-3_0.3.3-1build3_amd64.deb ...
Unpacking libwpg-0.3-3:amd64 (0.3.3-1build3) ...
```

```
Selecting previously unselected package inkscape.
Preparing to unpack .../62-inkscape_1.1.2-3ubuntu1_amd64.deb ...
Unpacking inkscape (1.1.2-3ubuntu1) ...
Selecting previously unselected package libdjvulibre-text.
Preparing to unpack .../63-libdjvulibre-text_3.5.28-2build2_all.deb ...
Unpacking libdjvulibre-text (3.5.28-2build2) ...
Selecting previously unselected package libdjvulibre21:amd64.
Preparing to unpack .../64-libdjvulibre21_3.5.28-2build2_amd64.deb ...
Unpacking libdjvulibre21:amd64 (3.5.28-2build2) ...
Selecting previously unselected package libjxr0:amd64.
Preparing to unpack .../65-libjxr0_1.2~git20170615.f752187-5_amd64.deb ...
Unpacking libjxr0:amd64 (1.2~git20170615.f752187-5) ...
Selecting previously unselected package libjxr-tools.
Preparing to unpack .../66-libjxr-tools_1.2~git20170615.f752187-5_amd64.deb ...
Unpacking libjxr-tools (1.2~git20170615.f752187-5) ...
Selecting previously unselected package libwmflite-0.2-7:amd64.
Preparing to unpack .../67-libwmflite-0.2-7_0.2.12-5ubuntu1_amd64.deb ...
Unpacking libwmflite-0.2-7:amd64 (0.2.12-5ubuntu1) ...
Selecting previously unselected package libmagickcore-6.q16-6-extra:amd64.
Preparing to unpack .../68-libmagickcore-6.q16-6-extra_8%3a6.9.11.60+dfsg-1.3ubuntu0.22.04.5_amd64.deb ...
Unpacking libmagickcore-6.q16-6-extra:amd64
(8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Selecting previously unselected package libwmf-0.2-7:amd64.
Preparing to unpack .../69-libwmf-0.2-7_0.2.12-5ubuntu1_amd64.deb ...
Unpacking libwmf-0.2-7:amd64 (0.2.12-5ubuntu1) ...
Selecting previously unselected package libwmf-bin.
Preparing to unpack .../70-libwmf-bin_0.2.12-5ubuntu1_amd64.deb ...
Unpacking libwmf-bin (0.2.12-5ubuntu1) ...
Selecting previously unselected package python3-soupsieve.
Preparing to unpack .../71-python3-soupsieve_2.3.1-1_all.deb ...
Unpacking python3-soupsieve (2.3.1-1) ...
Selecting previously unselected package python3-bs4.
Preparing to unpack .../72-python3-bs4_4.10.0-2_all.deb ...
Unpacking python3-bs4 (4.10.0-2) ...
Selecting previously unselected package python3-chardet.
Preparing to unpack .../73-python3-chardet_4.0.0-1_all.deb ...
Unpacking python3-chardet (4.0.0-1) ...
Selecting previously unselected package python3-webencodings.
Preparing to unpack .../74-python3-webencodings_0.5.1-4_all.deb ...
Unpacking python3-webencodings (0.5.1-4) ...
Selecting previously unselected package python3-html5lib.
Preparing to unpack .../75-python3-html5lib_1.1-3_all.deb ...
Unpacking python3-html5lib (1.1-3) ...
Selecting previously unselected package python3-lxml:amd64.
Preparing to unpack .../76-python3-lxml_4.8.0-1build1_amd64.deb ...
Unpacking python3-lxml:amd64 (4.8.0-1build1) ...
Selecting previously unselected package python3-numpy.
```

```
Preparing to unpack .../77-python3-numpy_1%3a1.21.5-1ubuntu22.04.1_amd64.deb ...
Unpacking python3-numpy (1:1.21.5-1ubuntu22.04.1) ...
Selecting previously unselected package python3-scour.
Preparing to unpack .../78-python3-scour_0.38.2-2_all.deb ...
Unpacking python3-scour (0.38.2-2) ...
Setting up libtext-iconv-perl (1.7-7build3) ...
Setting up session-migration (0.3.6) ...
Created symlink /etc/systemd/user/graphical-session-pre.target.wants/session-
migration.service → /usr/lib/systemd/user/session-migration.service.
Setting up imagemagick-6-common (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Setting up libproxy1v5:amd64 (0.4.17-2) ...
Setting up libpoppler-glib8:amd64 (22.02.0-2ubuntu0.8) ...
Setting up fonts-noto-mono (20201225-1build1) ...
Setting up libwmflite-0.2-7:amd64 (0.2.12-5ubuntu1) ...
Setting up libgslcblas0:amd64 (2.7.1+dfsg-3) ...
Setting up libgspell-1-common (1.9.1-4) ...
Setting up dictionaries-common (1.28.14) ...
Setting up gawk (1:5.1.0-1ubuntu0.1) ...
Setting up libaspell15:amd64 (0.60.8-4build1) ...
Setting up libijs-0.35:amd64 (0.35-15build2) ...
Setting up libjxr0:amd64 (1.2~git20170615.f752187-5) ...
Setting up libgsl27:amd64 (2.7.1+dfsg-3) ...
Setting up libnetpbm10 (2:10.0-15.4) ...
Setting up fonts-urw-base35 (20200910-1) ...
Setting up python3-webencodings (0.5.1-4) ...
Setting up librevenge-0.0-0:amd64 (0.0.4-6ubuntu7) ...
Setting up poppler-data (0.4.11-1) ...
Setting up python3-chardet (4.0.0-1) ...
Setting up libwmf-0.2-7:amd64 (0.2.12-5ubuntu1) ...
Setting up libjbig2dec0:amd64 (0.19-3build2) ...
Setting up libsigc++-2.0-0v5:amd64 (2.10.4-2ubuntu3) ...
Setting up libdbus-glib-1-2:amd64 (0.112-2build1) ...
Setting up gsfonts (1:8.11+urwcyr1.0.7~pre44-4.5) ...
Setting up libidn12:amd64 (1.38-4ubuntu1) ...
Setting up lib2geom1.1.0:amd64 (1.1-2build1) ...
Setting up aspell (0.60.8-4build1) ...
Setting up librsvg2-common:amd64 (2.52.5+dfsg-3ubuntu0.2) ...
Setting up netpbm (2:10.0-15.4) ...
Setting up python3-html5lib (1.1-3) ...
Setting up python3-numpy (1:1.21.5-1ubuntu22.04.1) ...
Setting up libfftw3-double3:amd64 (3.3.8-2ubuntu8) ...
Setting up libsoup2.4-common (2.74.2-3ubuntu0.5) ...
Setting up liblqr-1-0:amd64 (0.4.2-2.1) ...
Setting up python3-lxml:amd64 (4.8.0-1build1) ...
Setting up hunspell-en-us (1:2020.12.07-2) ...
Setting up fonts-droid-fallback (1:6.0.1r16-1.1build1) ...
Setting up python3-scour (0.38.2-2) ...
Setting up libdjvuibre-text (3.5.28-2build2) ...
```

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Setting up libhunspell-1.7-0:amd64 (1.7.0-4build1) ...
Setting up glib-networking-common (2.72.0-1) ...
Setting up libwpd-0.10-10:amd64 (0.10.3-2build1) ...
Setting up python3-soupsieve (2.3.1-1) ...
Setting up libvisio-0.1-1:amd64 (0.1.7-1build5) ...
Setting up libpotrace0:amd64 (1.16-2) ...
Setting up libgs9-common (9.55.0~dfsg1-0ubuntu5.11) ...
Setting up gsettings-desktop-schemas (42.0-1ubuntu1) ...
Setting up glib-networking-services (2.72.0-1) ...
Setting up libglibmm-2.4-1v5:amd64 (2.66.2-2) ...
Setting up libwmf-bin (0.2.12-5ubuntu1) ...
Setting up libjxr-tools (1.2~git20170615.f752187-5) ...
Setting up libgs9:amd64 (9.55.0~dfsg1-0ubuntu5.11) ...
Setting up libenchant-2-2:amd64 (2.3.2-1ubuntu2) ...
Setting up libdjvuibre21:amd64 (3.5.28-2build2) ...
Setting up aspell-en (2018.04.16-0-1) ...
Setting up enchant-2 (2.3.2-1ubuntu2) ...
Setting up libcdr-0.1-1:amd64 (0.1.6-2build2) ...
Setting up ghostscript (9.55.0~dfsg1-0ubuntu5.11) ...
Setting up fig2dev (1:3.2.8b-1) ...
Setting up python3-bs4 (4.10.0-2) ...
Setting up libcairomm-1.0-1v5:amd64 (1.12.2-4build3) ...
Setting up libmagickcore-6.q16-6:amd64 (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Setting up libpangomm-1.4-1v5:amd64 (2.46.2-1) ...
Setting up libwpg-0.3-3:amd64 (0.3.3-1build3) ...
Setting up libmagickwand-6.q16-6:amd64 (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Setting up libatkmm-1.6-1v5:amd64 (2.28.2-1build1) ...
Setting up libmagick++-6.q16-8:amd64 (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Setting up libgspell-1-2:amd64 (1.9.1-4) ...
Setting up libmagickcore-6.q16-6-extra:amd64
(8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Setting up libimage-magick-q16-perl (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Setting up libgtkmm-3.0-1v5:amd64 (3.24.5-1build1) ...
Setting up imagemagick-6.q16 (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
update-alternatives: using /usr/bin/compare-im6.q16 to provide /usr/bin/compare
(compare) in auto mode
update-alternatives: using /usr/bin/compare-im6.q16 to provide /usr/bin/compare-
im6 (compare-im6) in auto mode
update-alternatives: using /usr/bin/animate-im6.q16 to provide /usr/bin/animate
/animate) in auto mode
update-alternatives: using /usr/bin/animate-im6.q16 to provide /usr/bin/animate-
im6 (animate-im6) in auto mode
update-alternatives: using /usr/bin/convert-im6.q16 to provide /usr/bin/convert
(convert) in auto mode
update-alternatives: using /usr/bin/convert-im6.q16 to provide /usr/bin/convert-
im6 (convert-im6) in auto mode
update-alternatives: using /usr/bin/composite-im6.q16 to provide
/usr/bin/composite (composite) in auto mode
```

```
update-alternatives: using /usr/bin/composite-im6.q16 to provide
/usr/bin/composite-im6 (composite-im6) in auto mode
update-alternatives: using /usr/bin/conjure-im6.q16 to provide /usr/bin/conjure
(conjure) in auto mode
update-alternatives: using /usr/bin/conjure-im6.q16 to provide /usr/bin/conjure-
im6 (conjure-im6) in auto mode
update-alternatives: using /usr/bin/import-im6.q16 to provide /usr/bin/import
(import) in auto mode
update-alternatives: using /usr/bin/import-im6.q16 to provide /usr/bin/import-
im6 (import-im6) in auto mode
update-alternatives: using /usr/bin/identify-im6.q16 to provide
/usr/bin/identify (identify) in auto mode
update-alternatives: using /usr/bin/identify-im6.q16 to provide
/usr/bin/identify-im6 (identify-im6) in auto mode
update-alternatives: using /usr/bin/stream-im6.q16 to provide /usr/bin/stream
(stream) in auto mode
update-alternatives: using /usr/bin/stream-im6.q16 to provide /usr/bin/stream-
im6 (stream-im6) in auto mode
update-alternatives: using /usr/bin/display-im6.q16 to provide /usr/bin/display
(display) in auto mode
update-alternatives: using /usr/bin/display-im6.q16 to provide /usr/bin/display-
im6 (display-im6) in auto mode
update-alternatives: using /usr/bin/montage-im6.q16 to provide /usr/bin/montage
(montage) in auto mode
update-alternatives: using /usr/bin/montage-im6.q16 to provide /usr/bin/montage-
im6 (montage-im6) in auto mode
update-alternatives: using /usr/bin/mogrify-im6.q16 to provide /usr/bin/mogrify
(mogrify) in auto mode
update-alternatives: using /usr/bin/mogrify-im6.q16 to provide /usr/bin/mogrify-
im6 (mogrify-im6) in auto mode
Setting up libimage-magick-perl (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Setting up imagemagick (8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5) ...
Processing triggers for libgdk-pixbuf-2.0-0:amd64 (2.42.8+dfsg-1ubuntu0.3) ...
Processing triggers for mailcap (3.70+nmu1ubuntu1) ...
Processing triggers for fontconfig (2.13.1-4.2ubuntu5) ...
Processing triggers for hicolor-icon-theme (0.17-2) ...
Processing triggers for libglib2.0-0:amd64 (2.72.4-0ubuntu2.5) ...
Processing triggers for libc-bin (2.35-0ubuntu3.8) ...
/sbin/ldconfig.real: /usr/local/lib/libtbb.so.12 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libtcm_debug.so.1 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libur_loader.so.0 is not a symbolic link

/sbin/ldconfig.real: /usr/local/lib/libur_adapter_opencncl.so.0 is not a symbolic
link

/sbin/ldconfig.real: /usr/local/lib/libhwloc.so.15 is not a symbolic link
```

```
/sbin/ldconfig.real: /usr/local/lib/libtbbbind_2_5.so.3 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbbind_2_0.so.3 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtcm.so.1 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc.so.2 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libumf.so.0 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libur_adapter_level_zero.so.0 is not a
symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbbind.so.3 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc_proxy.so.2 is not a symbolic
link

Processing triggers for man-db (2.10.2-1) ...
Setting up glib-networking:amd64 (2.72.0-1) ...
Setting up libsoup2.4-1:amd64 (2.74.2-3ubuntu0.5) ...
Setting up inkscape (1.1.2-3ubuntu1) ...
Processing triggers for dictionaries-common (1.28.14) ...
aspell-autobuildhash: processing: en [en-common].
aspell-autobuildhash: processing: en [en-variant_0].
aspell-autobuildhash: processing: en [en-variant_1].
aspell-autobuildhash: processing: en [en-variant_2].
aspell-autobuildhash: processing: en [en-w_accents-only].
aspell-autobuildhash: processing: en [en-wo_accents-only].
aspell-autobuildhash: processing: en [en_AU-variant_0].
aspell-autobuildhash: processing: en [en_AU-variant_1].
aspell-autobuildhash: processing: en [en_AU-w_accents-only].
aspell-autobuildhash: processing: en [en_AU-wo_accents-only].
aspell-autobuildhash: processing: en [en_CA-variant_0].
aspell-autobuildhash: processing: en [en_CA-variant_1].
aspell-autobuildhash: processing: en [en_CA-w_accents-only].
aspell-autobuildhash: processing: en [en_CA-wo_accents-only].
aspell-autobuildhash: processing: en [en_GB-ise-w_accents-only].
aspell-autobuildhash: processing: en [en_GB-ise-wo_accents-only].
aspell-autobuildhash: processing: en [en_GB-ize-w_accents-only].
aspell-autobuildhash: processing: en [en_GB-ize-wo_accents-only].
aspell-autobuildhash: processing: en [en_GB-variant_0].
aspell-autobuildhash: processing: en [en_GB-variant_1].
aspell-autobuildhash: processing: en [en_US-w_accents-only].
aspell-autobuildhash: processing: en [en_US-wo_accents-only].
Processing triggers for libc-bin (2.35-0ubuntu3.8) ...
/sbin/ldconfig.real: /usr/local/lib/libtbb.so.12 is not a symbolic link
```

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/sbin/ldconfig.real: /usr/local/lib/libtcm_debug.so.1 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libur_loader.so.0 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libur_adapter_opencl.so.0 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libhwloc.so.15 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbbind_2_5.so.3 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbbind_2_0.so.3 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtcm.so.1 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc.so.2 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libumf.so.0 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libur_adapter_level_zero.so.0 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbbind.so.3 is not a symbolic link
/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc_proxy.so.2 is not a symbolic link

Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
The following additional packages will be installed:
  dvisvgm fonts-lato fonts-lmodern fonts-texgyre libapache-pom-jar
  libcommons-logging-jar libcommons-parent-jar libfontbox-jar libkpathsea6
  libpdfbox-jar libptexenc1 libruby3.0 libsynctex2 libteckit0 libtexlua53
  libtexluajit2 libwoff1 libzzip-0-13 lmodern preview-latex-style rake ruby
  ruby-net-telnet ruby-rubygems ruby-webrick ruby-xmlrpc ruby3.0
  rubygems-integration t1utils teckit tex-common tex-gyre texlive-base
  texlive-binaries texlive-latex-base texlive-latex-recommended
  texlive-pictures texlive-plain-generic tipa xfonts-encodings xfonts-utils
Suggested packages:
  libavalon-framework-jar libcommons-logging-jar-doc
  libexcalibur-logkit-jar liblog4j1.2-jar ri ruby-dev bundler debhelper
  perl-tk xpdf | pdf-viewer xzdec texlive-fonts-recommended-doc
  texlive-latex-base-doc python3-pygments icc-profiles libfile-which-perl
  libspreadsheet-parseexcel-perl texlive-latex-extra-doc
  texlive-latex-recommended-doc texlive-luatex texlive-pstricks dot2tex prerex
  texlive-pictures-doc vprerex default-jre-headless tipa-doc
```

The following NEW packages will be installed:

```

dvisvgm fonts-lato fonts-lmodern fonts-texgyre libapache-pom-java
libcommons-logging-java libcommons-parent-java libfontbox-java libkpathsea6
libpdfbox-java libptexenc1 libruby3.0 libsynctex2 libteckit0 libtexlua53
libtexluajit2 libwoff1 libzip-0-13 lmodern preview-latex-style rake ruby
ruby-net-telnet ruby-rubygems ruby-webbrick ruby-xmlrpc ruby3.0
rubygems-integration t1utils teckit tex-common tex-gyre texlive-base
texlive-binaries texlive-fonts-recommended texlive-latex-base
texlive-latex-extra texlive-latex-recommended texlive-pictures
texlive-plain-generic texlive-xetex tipa xfonts-encodings xfonts-utils

```

0 upgraded, 44 newly installed, 0 to remove and 37 not upgraded.

Need to get 165 MB of archives.

After this operation, 509 MB of additional disk space will be used.

```

Get:1 http://archive.ubuntu.com/ubuntu jammy/main amd64 fonts-lato all 2.0-2.1
[2,696 kB]
Get:2 http://archive.ubuntu.com/ubuntu jammy/universe amd64 tex-common all 6.17
[33.7 kB]
Get:3 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libkpathsea6
amd64 2021.20210626.59705-1ubuntu0.2 [60.4 kB]
Get:4 http://archive.ubuntu.com/ubuntu jammy/main amd64 libwoff1 amd64
1.0.2-1build4 [45.2 kB]
Get:5 http://archive.ubuntu.com/ubuntu jammy/universe amd64 dvisvgm amd64
2.13.1-1 [1,221 kB]
Get:6 http://archive.ubuntu.com/ubuntu jammy/universe amd64 fonts-lmodern all
2.004.5-6.1 [4,532 kB]
Get:7 http://archive.ubuntu.com/ubuntu jammy/universe amd64 fonts-texgyre all
20180621-3.1 [10.2 MB]
Get:8 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libapache-pom-java
all 18-1 [4,720 B]
Get:9 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libcommons-parent-
java all 43-1 [10.8 kB]
Get:10 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libcommons-logging-
java all 1.2-2 [60.3 kB]
Get:11 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libptexenc1
amd64 2021.20210626.59705-1ubuntu0.2 [39.1 kB]
Get:12 http://archive.ubuntu.com/ubuntu jammy/main amd64 rubygems-integration
all 1.18 [5,336 B]
Get:13 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 ruby3.0 amd64
3.0.2-7ubuntu2.10 [50.1 kB]
Get:14 http://archive.ubuntu.com/ubuntu jammy/main amd64 ruby-rubygems all
3.3.5-2 [228 kB]
Get:15 http://archive.ubuntu.com/ubuntu jammy/main amd64 ruby amd64 1:3.0~exp1
[5,100 B]
Get:16 http://archive.ubuntu.com/ubuntu jammy/main amd64 rake all 13.0.6-2 [61.7
kB]
Get:17 http://archive.ubuntu.com/ubuntu jammy/main amd64 ruby-net-telnet all
0.1.1-2 [12.6 kB]
Get:18 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 ruby-webbrick

```

all 1.7.0-3ubuntu0.1 [52.1 kB]
Get:19 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 ruby-xmlrpc all
0.3.2-1ubuntu0.1 [24.9 kB]
Get:20 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libruby3.0
amd64 3.0.2-7ubuntu2.10 [5,114 kB]
Get:21 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libsynctex2
amd64 2021.20210626.59705-1ubuntu0.2 [55.6 kB]
Get:22 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libteckit0 amd64
2.5.11+ds1-1 [421 kB]
Get:23 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libtexlua53
amd64 2021.20210626.59705-1ubuntu0.2 [120 kB]
Get:24 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 libtexluajit2
amd64 2021.20210626.59705-1ubuntu0.2 [267 kB]
Get:25 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libzzip-0-13 amd64
0.13.72+dfsg.1-1.1 [27.0 kB]
Get:26 http://archive.ubuntu.com/ubuntu jammy/main amd64 xfonts-encodings all
1:1.0.5-0ubuntu2 [578 kB]
Get:27 http://archive.ubuntu.com/ubuntu jammy/main amd64 xfonts-utils amd64
1:7.7+6build2 [94.6 kB]
Get:28 http://archive.ubuntu.com/ubuntu jammy/universe amd64 lmodern all
2.004.5-6.1 [9,471 kB]
Get:29 http://archive.ubuntu.com/ubuntu jammy/universe amd64 preview-latex-style
all 12.2-1ubuntu1 [185 kB]
Get:30 http://archive.ubuntu.com/ubuntu jammy/main amd64 t1utils amd64
1.41-4build2 [61.3 kB]
Get:31 http://archive.ubuntu.com/ubuntu jammy/universe amd64 teckit amd64
2.5.11+ds1-1 [699 kB]
Get:32 http://archive.ubuntu.com/ubuntu jammy/universe amd64 tex-gyre all
20180621-3.1 [6,209 kB]
Get:33 http://archive.ubuntu.com/ubuntu jammy-updates/universe amd64 texlive-
binaries amd64 2021.20210626.59705-1ubuntu0.2 [9,860 kB]
Get:34 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-base all
2021.20220204-1 [21.0 MB]
Get:35 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-fonts-
recommended all 2021.20220204-1 [4,972 kB]
Get:36 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-latex-base
all 2021.20220204-1 [1,128 kB]
Get:37 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libfontbox-java all
1:1.8.16-2 [207 kB]
Get:38 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libpdfbox-java all
1:1.8.16-2 [5,199 kB]
Get:39 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-latex-
recommended all 2021.20220204-1 [14.4 MB]
Get:40 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-pictures
all 2021.20220204-1 [8,720 kB]
Get:41 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-latex-extra
all 2021.20220204-1 [13.9 MB]
Get:42 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-plain-

```
generic all 2021.20220204-1 [27.5 MB]
Get:43 http://archive.ubuntu.com/ubuntu jammy/universe amd64 tipa all 2:1.3-21
[2,967 kB]
Get:44 http://archive.ubuntu.com/ubuntu jammy/universe amd64 texlive-xetex all
2021.20220204-1 [12.4 MB]
Fetched 165 MB in 4s (41.9 MB/s)
Extracting templates from packages: 100%
Preconfiguring packages ...
Selecting previously unselected package fonts-lato.
(Reading database ... 133823 files and directories currently installed.)
Preparing to unpack .../00-fonts-lato_2.0-2.1_all.deb ...
Unpacking fonts-lato (2.0-2.1) ...
Selecting previously unselected package tex-common.
Preparing to unpack .../01-tex-common_6.17_all.deb ...
Unpacking tex-common (6.17) ...
Selecting previously unselected package libkpathsea6:amd64.
Preparing to unpack .../02-libkpathsea6_2021.20210626.59705-1ubuntu0.2_amd64.deb
...
Unpacking libkpathsea6:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package libwoff1:amd64.
Preparing to unpack .../03-libwoff1_1.0.2-1build4_amd64.deb ...
Unpacking libwoff1:amd64 (1.0.2-1build4) ...
Selecting previously unselected package dvisvgm.
Preparing to unpack .../04-dvisvgm_2.13.1-1_amd64.deb ...
Unpacking dvisvgm (2.13.1-1) ...
Selecting previously unselected package fonts-lmodern.
Preparing to unpack .../05-fonts-lmodern_2.004.5-6.1_all.deb ...
Unpacking fonts-lmodern (2.004.5-6.1) ...
Selecting previously unselected package fonts-texgyre.
Preparing to unpack .../06-fonts-texgyre_20180621-3.1_all.deb ...
Unpacking fonts-texgyre (20180621-3.1) ...
Selecting previously unselected package libapache-pom-java.
Preparing to unpack .../07-libapache-pom-java_18-1_all.deb ...
Unpacking libapache-pom-java (18-1) ...
Selecting previously unselected package libcommons-parent-java.
Preparing to unpack .../08-libcommons-parent-java_43-1_all.deb ...
Unpacking libcommons-parent-java (43-1) ...
Selecting previously unselected package libcommons-logging-java.
Preparing to unpack .../09-libcommons-logging-java_1.2-2_all.deb ...
Unpacking libcommons-logging-java (1.2-2) ...
Selecting previously unselected package libptexenc1:amd64.
Preparing to unpack .../10-libptexenc1_2021.20210626.59705-1ubuntu0.2_amd64.deb
...
Unpacking libptexenc1:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package rubygems-integration.
Preparing to unpack .../11-rubygems-integration_1.18_all.deb ...
Unpacking rubygems-integration (1.18) ...
Selecting previously unselected package ruby3.0.
```

```
Preparing to unpack .../12-ruby3.0_3.0.2-7ubuntu2.10_amd64.deb ...
Unpacking ruby3.0 (3.0.2-7ubuntu2.10) ...
Selecting previously unselected package ruby-rubygems.
Preparing to unpack .../13-ruby-rubygems_3.3.5-2_all.deb ...
Unpacking ruby-rubygems (3.3.5-2) ...
Selecting previously unselected package ruby.
Preparing to unpack .../14-ruby_1%3a3.0~exp1_amd64.deb ...
Unpacking ruby (1:3.0~exp1) ...
Selecting previously unselected package rake.
Preparing to unpack .../15-rake_13.0.6-2_all.deb ...
Unpacking rake (13.0.6-2) ...
Selecting previously unselected package ruby-net-telnet.
Preparing to unpack .../16-ruby-net-telnet_0.1.1-2_all.deb ...
Unpacking ruby-net-telnet (0.1.1-2) ...
Selecting previously unselected package ruby-webrick.
Preparing to unpack .../17-ruby-webrick_1.7.0-3ubuntu0.1_all.deb ...
Unpacking ruby-webrick (1.7.0-3ubuntu0.1) ...
Selecting previously unselected package ruby-xmlrpc.
Preparing to unpack .../18-ruby-xmlrpc_0.3.2-1ubuntu0.1_all.deb ...
Unpacking ruby-xmlrpc (0.3.2-1ubuntu0.1) ...
Selecting previously unselected package libruby3.0:amd64.
Preparing to unpack .../19-libruby3.0_3.0.2-7ubuntu2.10_amd64.deb ...
Unpacking libruby3.0:amd64 (3.0.2-7ubuntu2.10) ...
Selecting previously unselected package libsynctex2:amd64.
Preparing to unpack .../20-libsynctex2_2021.20210626.59705-1ubuntu0.2_amd64.deb
...
Unpacking libsynctex2:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package libteckit0:amd64.
Preparing to unpack .../21-libteckit0_2.5.11+ds1-1_amd64.deb ...
Unpacking libteckit0:amd64 (2.5.11+ds1-1) ...
Selecting previously unselected package libtexlua53:amd64.
Preparing to unpack .../22-libtexlua53_2021.20210626.59705-1ubuntu0.2_amd64.deb
...
Unpacking libtexlua53:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package libtexluajit2:amd64.
Preparing to unpack
.../23-libtexluajit2_2021.20210626.59705-1ubuntu0.2_amd64.deb ...
Unpacking libtexluajit2:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package libzzip-0-13:amd64.
Preparing to unpack .../24-libzzip-0-13_0.13.72+dfsg.1-1.1_amd64.deb ...
Unpacking libzzip-0-13:amd64 (0.13.72+dfsg.1-1.1) ...
Selecting previously unselected package xfonts-encodings.
Preparing to unpack .../25-xfonts-encodings_1%3a1.0.5-0ubuntu2_all.deb ...
Unpacking xfonts-encodings (1:1.0.5-0ubuntu2) ...
Selecting previously unselected package xfonts-utils.
Preparing to unpack .../26-xfonts-utils_1%3a7.7+6build2_amd64.deb ...
Unpacking xfonts-utils (1:7.7+6build2) ...
Selecting previously unselected package lmodern.
```

```
Preparing to unpack .../27-lmodern_2.004.5-6.1_all.deb ...
Unpacking lmodern (2.004.5-6.1) ...
Selecting previously unselected package preview-latex-style.
Preparing to unpack .../28-preview-latex-style_12.2-1ubuntu1_all.deb ...
Unpacking preview-latex-style (12.2-1ubuntu1) ...
Selecting previously unselected package t1utils.
Preparing to unpack .../29-t1utils_1.41-4build2_amd64.deb ...
Unpacking t1utils (1.41-4build2) ...
Selecting previously unselected package teckit.
Preparing to unpack .../30-teckit_2.5.11+ds1-1_amd64.deb ...
Unpacking teckit (2.5.11+ds1-1) ...
Selecting previously unselected package tex-gyre.
Preparing to unpack .../31-tex-gyre_20180621-3.1_all.deb ...
Unpacking tex-gyre (20180621-3.1) ...
Selecting previously unselected package texlive-binaries.
Preparing to unpack .../32-texlive-
binaries_2021.20210626.59705-1ubuntu0.2_amd64.deb ...
Unpacking texlive-binaries (2021.20210626.59705-1ubuntu0.2) ...
Selecting previously unselected package texlive-base.
Preparing to unpack .../33-texlive-base_2021.20220204-1_all.deb ...
Unpacking texlive-base (2021.20220204-1) ...
Selecting previously unselected package texlive-fonts-recommended.
Preparing to unpack .../34-texlive-fonts-recommended_2021.20220204-1_all.deb ...
Unpacking texlive-fonts-recommended (2021.20220204-1) ...
Selecting previously unselected package texlive-latex-base.
Preparing to unpack .../35-texlive-latex-base_2021.20220204-1_all.deb ...
Unpacking texlive-latex-base (2021.20220204-1) ...
Selecting previously unselected package libfontbox-java.
Preparing to unpack .../36-libfontbox-java_1%3a1.8.16-2_all.deb ...
Unpacking libfontbox-java (1:1.8.16-2) ...
Selecting previously unselected package libpdfbox-java.
Preparing to unpack .../37-libpdfbox-java_1%3a1.8.16-2_all.deb ...
Unpacking libpdfbox-java (1:1.8.16-2) ...
Selecting previously unselected package texlive-latex-recommended.
Preparing to unpack .../38-texlive-latex-recommended_2021.20220204-1_all.deb ...
Unpacking texlive-latex-recommended (2021.20220204-1) ...
Selecting previously unselected package texlive-pictures.
Preparing to unpack .../39-texlive-pictures_2021.20220204-1_all.deb ...
Unpacking texlive-pictures (2021.20220204-1) ...
Selecting previously unselected package texlive-latex-extra.
Preparing to unpack .../40-texlive-latex-extra_2021.20220204-1_all.deb ...
Unpacking texlive-latex-extra (2021.20220204-1) ...
Selecting previously unselected package texlive-plain-generic.
Preparing to unpack .../41-texlive-plain-generic_2021.20220204-1_all.deb ...
Unpacking texlive-plain-generic (2021.20220204-1) ...
Selecting previously unselected package tipa.
Preparing to unpack .../42-tipa_2%3a1.3-21_all.deb ...
Unpacking tipa (2:1.3-21) ...
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Selecting previously unselected package texlive-xetex.
Preparing to unpack .../43-texlive-xetex_2021.20220204-1_all.deb ...
Unpacking texlive-xetex (2021.20220204-1) ...
Setting up fonts-lato (2.0-2.1) ...
Setting up libwoff1:amd64 (1.0.2-1build4) ...
Setting up libtexlua53:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up libtexluajit2:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up libfontbox-java (1:1.8.16-2) ...
Setting up rubygems-integration (1.18) ...
Setting up libzzip-0-13:amd64 (0.13.72+dfsg.1-1.1) ...
Setting up tex-common (6.17) ...
update-language: texlive-base not installed and configured, doing nothing!
Setting up libteckit0:amd64 (2.5.11+ds1-1) ...
Setting up libapache-pom-java (18-1) ...
Setting up ruby-net-telnet (0.1.1-2) ...
Setting up xfonts-encodings (1:1.0.5-0ubuntu2) ...
Setting up t1utils (1.41-4build2) ...
Setting up fonts-texgyre (20180621-3.1) ...
Setting up libkpathsea6:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up ruby-webrick (1.7.0-3ubuntu0.1) ...
Setting up fonts-lmodern (2.004.5-6.1) ...
Setting up ruby-xmlrpc (0.3.2-1ubuntu0.1) ...
Setting up libsynctex2:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up teckit (2.5.11+ds1-1) ...
Setting up libpdfbox-java (1:1.8.16-2) ...
Setting up preview-latex-style (12.2-1ubuntu1) ...
Setting up libcommons-parent-java (43-1) ...
Setting up dvisvgm (2.13.1-1) ...
Setting up libcommons-logging-java (1.2-2) ...
Setting up xfonts-utils (1:7.7+6build2) ...
Setting up libptexenc1:amd64 (2021.20210626.59705-1ubuntu0.2) ...
Setting up texlive-binaries (2021.20210626.59705-1ubuntu0.2) ...
update-alternatives: using /usr/bin/xdvi-xaw to provide /usr/bin/xdvi.bin
(xdvi.bin) in auto mode
update-alternatives: using /usr/bin/bibtex.original to provide /usr/bin/bibtex
(bibtex) in auto mode
Setting up lmodern (2.004.5-6.1) ...
Setting up texlive-base (2021.20220204-1) ...
/usr/bin/ucfr
/usr/bin/ucfr
/usr/bin/ucfr
/usr/bin/ucfr
mktexlsr: Updating /var/lib/texmf/ls-R-TEXLIVEDIST...
mktexlsr: Updating /var/lib/texmf/ls-R-TEXMFMAIN...
mktexlsr: Updating /var/lib/texmf/ls-R...
mktexlsr: Done.
tl-paper: setting paper size for dvips to a4:
/var/lib/texmf/dvips/config/config-paper.ps
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tl-paper: setting paper size for dvipdfmx to a4:  
/var/lib/texmf/dvipdfmx/dvipdfmx-paper.cfg  
tl-paper: setting paper size for xdvi to a4: /var/lib/texmf/xdvi/XDvi-paper  
tl-paper: setting paper size for pdftex to a4: /var/lib/texmf/tex/generic/tex-  
ini-files/pdftexconfig.tex  
Setting up tex-gyre (20180621-3.1) ...  
Setting up texlive-plain-generic (2021.20220204-1) ...  
Setting up texlive-latex-base (2021.20220204-1) ...  
Setting up texlive-latex-recommended (2021.20220204-1) ...  
Setting up texlive-pictures (2021.20220204-1) ...  
Setting up texlive-fonts-recommended (2021.20220204-1) ...  
Setting up tipa (2:1.3-21) ...  
Setting up texlive-latex-extra (2021.20220204-1) ...  
Setting up texlive-xetex (2021.20220204-1) ...  
Setting up rake (13.0.6-2) ...  
Setting up libruby3.0:amd64 (3.0.2-7ubuntu2.10) ...  
Setting up ruby3.0 (3.0.2-7ubuntu2.10) ...  
Setting up ruby (1:3.0~exp1) ...  
Setting up ruby-rubygems (3.3.5-2) ...  
Processing triggers for man-db (2.10.2-1) ...  
Processing triggers for mailcap (3.70+nmu1ubuntu1) ...  
Processing triggers for fontconfig (2.13.1-4.2ubuntu5) ...  
Processing triggers for libc-bin (2.35-0ubuntu3.8) ...  
/sbin/ldconfig.real: /usr/local/lib/libtbb.so.12 is not a symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libtcm_debug.so.1 is not a symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libur_loader.so.0 is not a symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libur_adapter_opencl.so.0 is not a symbolic  
link  
  
/sbin/ldconfig.real: /usr/local/lib/libhwloc.so.15 is not a symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libtbbbind_2_5.so.3 is not a symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libtbbbind_2_0.so.3 is not a symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libtcm.so.1 is not a symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc.so.2 is not a symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libumf.so.0 is not a symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libur_adapter_level_zero.so.0 is not a  
symbolic link  
  
/sbin/ldconfig.real: /usr/local/lib/libtbbbind.so.3 is not a symbolic link
```

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/sbin/ldconfig.real: /usr/local/lib/libtbbmalloc_proxy.so.2 is not a symbolic link
```

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Processing triggers for tex-common (6.17) ...
Running updmap-sys. This may take some time... done.
Running mktexlsr /var/lib/texmf ... done.
Building format(s) --all.
      This may take some time... done.
```

```
[ ]: %shell jupyter nbconvert --to pdf '/content/drive/MyDrive/Colab Notebooks/Ravi_U
˓→Teja Kothuru_Final Project AAI-510 Section IN2-Team 14.ipynb'
```

```
[NbConvertApp] Converting notebook /content/drive/MyDrive/Colab Notebooks/Ravi
Teja Kothuru_Final Project AAI-510 Section IN2-Team 14.ipynb to pdf
[WARNING] Could not parse YAML metadata at line 70 column 1: not an object
[WARNING] Could not parse YAML metadata at line 82 column 1: not an object
[WARNING] Could not parse YAML metadata at line 123 column 1: not an object
[NbConvertApp] Support files will be in Ravi Teja Kothuru_Final Project AAI-510
Section IN2-Team 14_files/
[NbConvertApp] Making directory ./Ravi Teja Kothuru_Final Project AAI-510
Section IN2-Team 14_files
[NbConvertApp] Writing 652121 bytes to notebook.tex
[NbConvertApp] Building PDF
[NbConvertApp] Running xelatex 3 times: ['xelatex', 'notebook.tex', '-quiet']
```