

# Ravi Teja Kothuru\_Final Project AAI-510 Section IN2-Team 14

June 22, 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 1440 files: 60 trials per actor x 24 actors = 1440. The RAVDESS contains 24 professional actors (12 female, 12 male), vocalizing two lexically-matched statements in a neutral North American accent. Speech emotions includes calm, happy, sad, angry, fearful, surprise, and disgust expressions. Each expression is produced at two levels of emotional intensity (normal, strong), with an additional neutral expression.
- **File naming conventions:** Each of the 1440 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

```
[3]: 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_Emotiona_l_Speech_Audio_Dataset.zip' -d '/content/
    ↵extracted_speech_audio_dataset'
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Archive:  
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 learning - Fundamentals and Applications/AAI-510-IN2\_Final  
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/content/extracted_speech_audio_dataset/Actor_24/03-01-05-02-01-02-24.wav  
    inflating:  
/content/extracted_speech_audio_dataset/Actor_24/03-01-05-02-02-01-24.wav  
    inflating:  
/content/extracted_speech_audio_dataset/Actor_24/03-01-05-02-02-02-24.wav  
    inflating:  
/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:  
/content/extracted_speech_audio_dataset/Actor_24/03-01-08-02-02-02-24.wav  
      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_01/03-01-01-02-02-01.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_01/03-01-02-02-02-01.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_01/03-01-02-02-01-02-01.wav  
      inflating: /content/extracted_speech_audio_dataset/audio_speech_actors_01-  
24/Actor_01/03-01-02-02-01-01-01.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
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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.
Pitch	Perceived audio signal frequency, often in Hertz (Hz).	High frequency may show an emotion like <i>surprise</i> or <i>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</i> or <i>happy</i> speech. Low or medium energy is likely for example with <i>sad</i> or <i>neutral</i> speech.
ZCR Crossing Rate)	The number of times the audio signal changes (Zero sign (crosses the zero line) over time.	Higher zero crossing rate might represent noise yet also excited speech (like <i>surprise</i> , or <i>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 Frequency Coefficients)	A compact representation of the short-term (Mel- power spectrum of a sound, modelled on human hearing (mel scale). Cepstral	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., 1500 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()

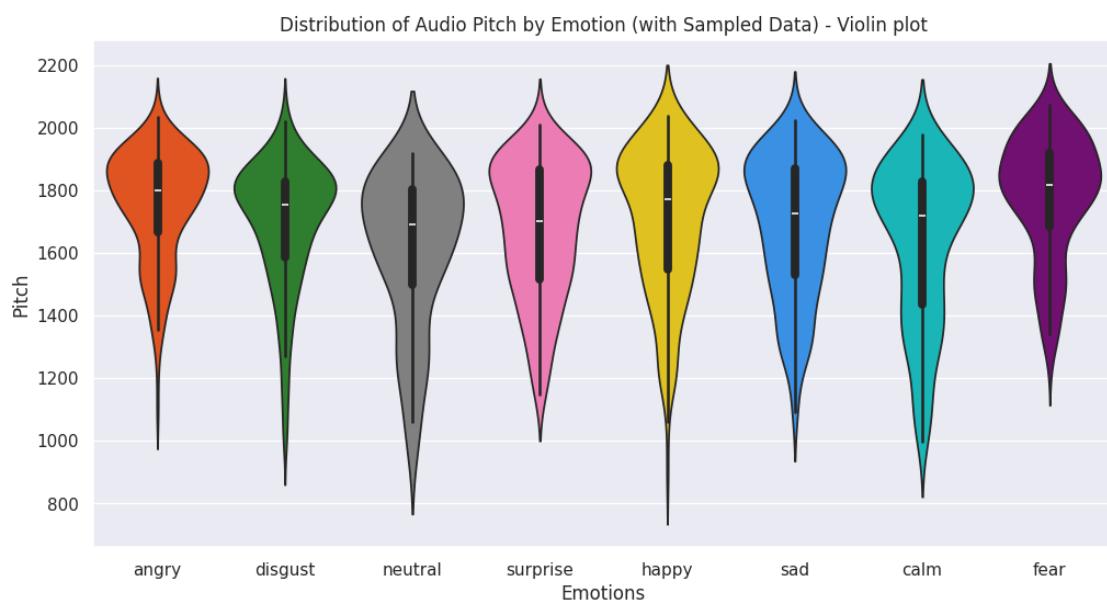
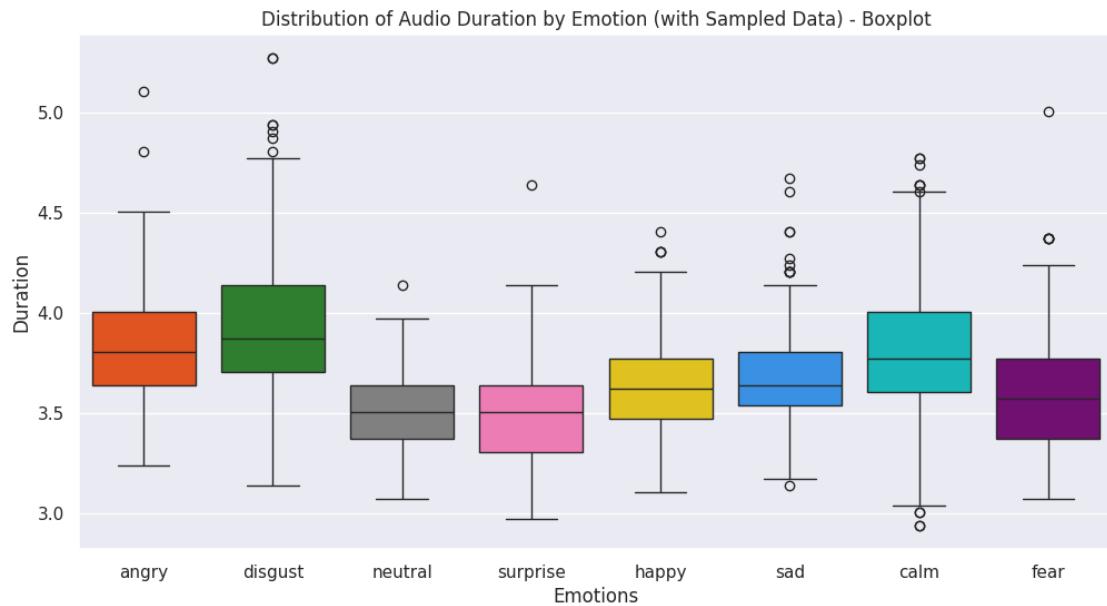
# ZCR - Boxplot
plt.figure(figsize=(12, 6))
sns.boxplot(x='Emotions', y='ZCR', data=sample_audio_data, ▾
            palette=custom_palette)

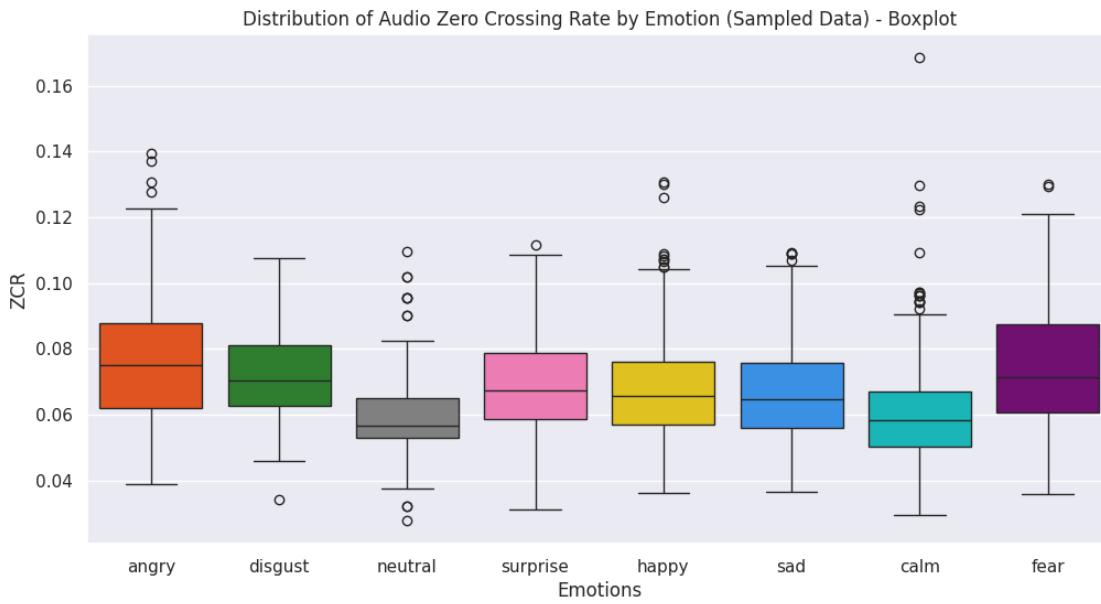
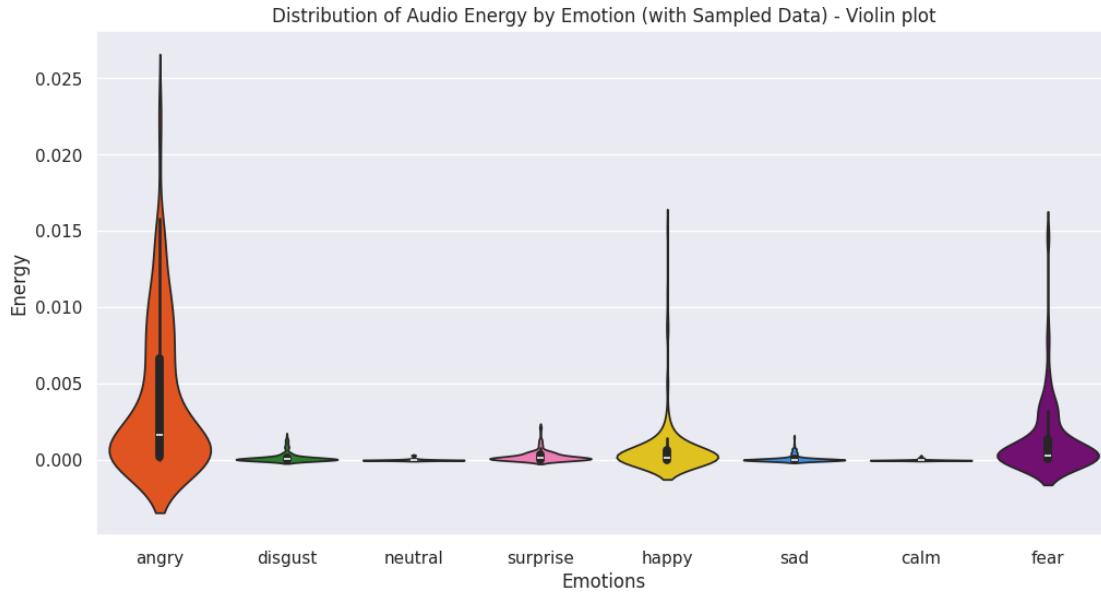
```

```

plt.title("Distribution of Audio Zero Crossing Rate by Emotion (Sampled Data) -_u
    ↪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
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

Model Name	Type	Notes
Extra Trees	Ensemble - Randomized Trees	Faster, more ran- domized than Random Forest
Gradient Boosting	Ensemble - Boosting	Models sequen- tially and often performs well from the start
XGBoost	Optimized Gradient Boosting	High per- formance, 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

Model Name	Type	Notes
Bagging	Ensemble - Bagging	Averages predictions in order to decrease variance
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
<b>Confusion Matrix</b>	Shows how frequently predictions are correct per class
<b>ROC-AUC Curve</b>	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]} □
    ↪(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}', □
    ↪fontsize=12)
            axes[1].set_xlabel("False Positive Rate")
            axes[1].set_ylabel("True Positive Rate")
            axes[1].legend(fontsize=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', fontsize=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,)
```

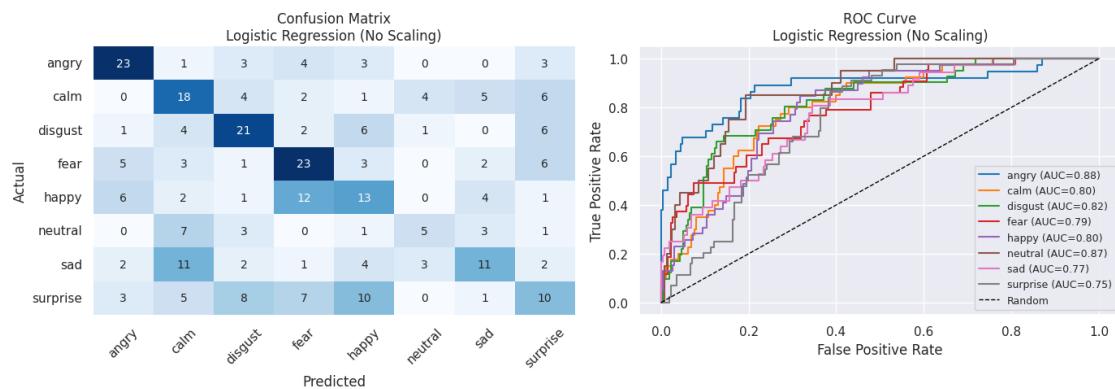
```
[ ]: y_test.shape
```

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

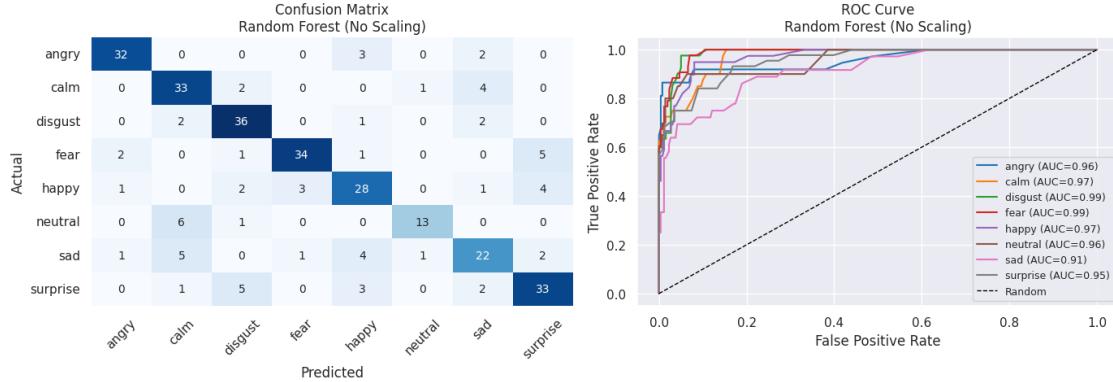
### 9.7.2 Train models and plot results without *StandardScaler*

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

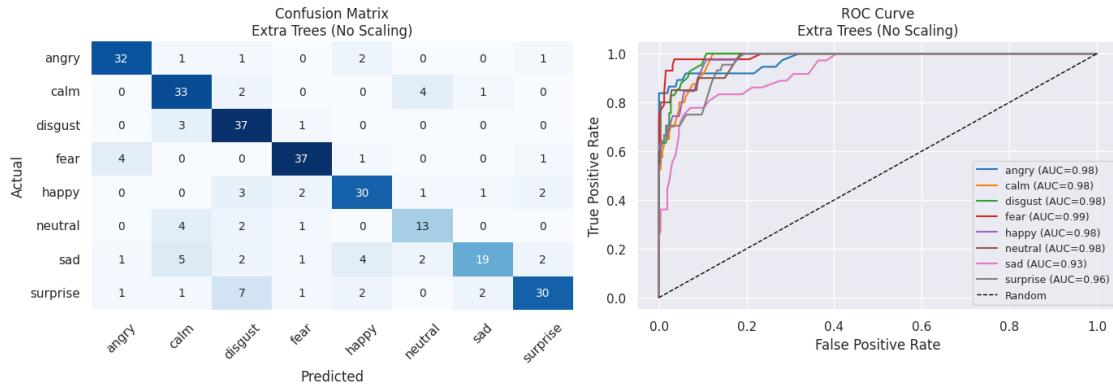
Training Logistic Regression (No Scaling)...



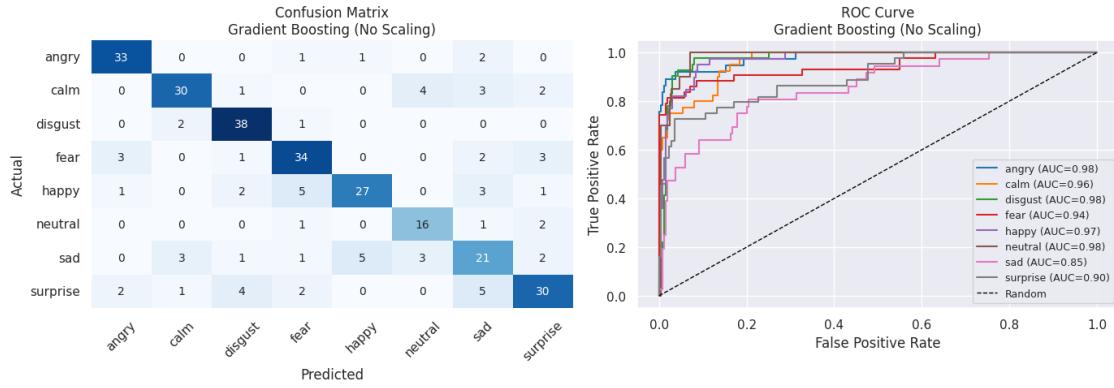
### Training Random Forest (No Scaling)...



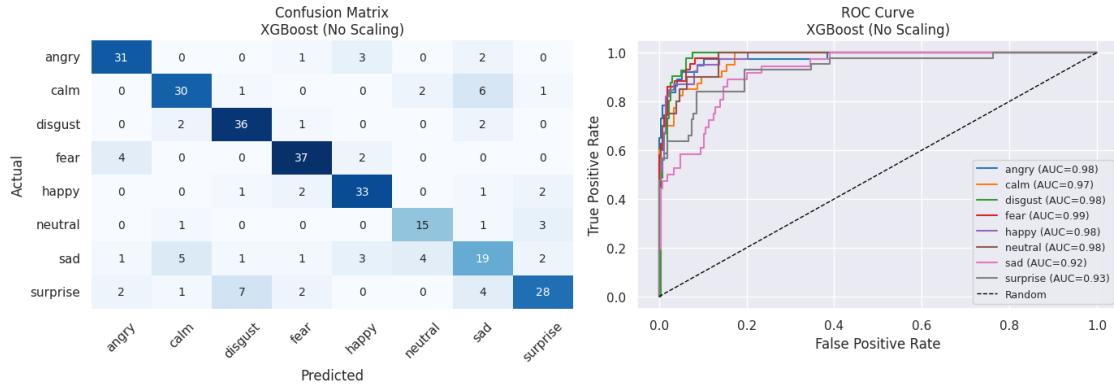
### Training Extra Trees (No Scaling)...



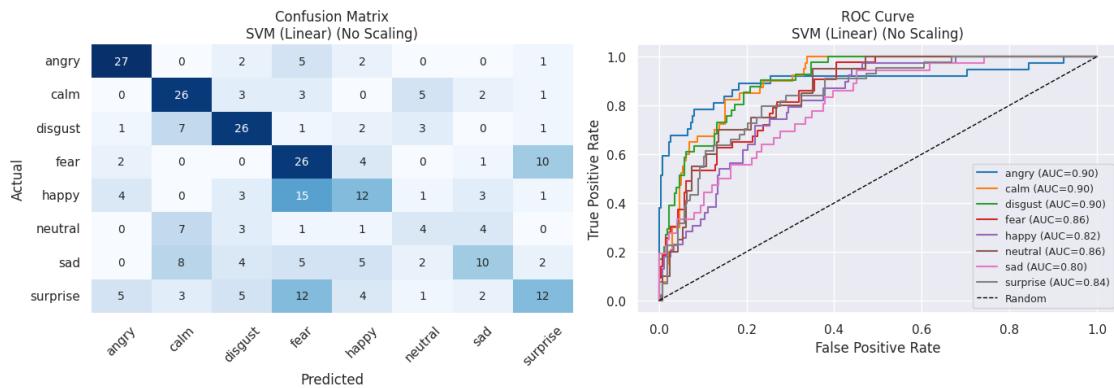
### Training Gradient Boosting (No Scaling)...



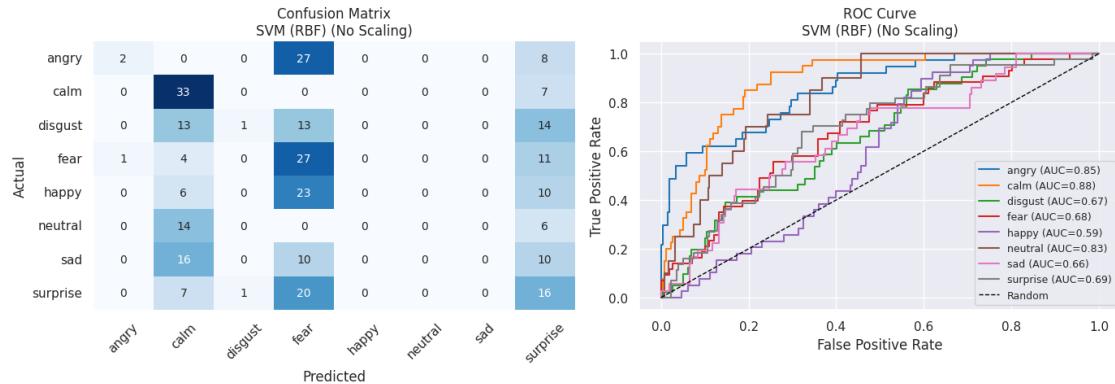
Training XGBoost (No Scaling)...



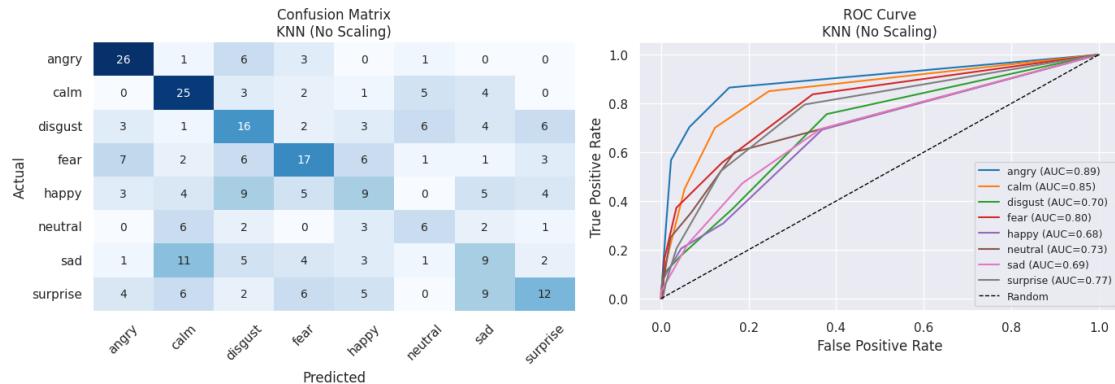
Training SVM (Linear) (No Scaling)...



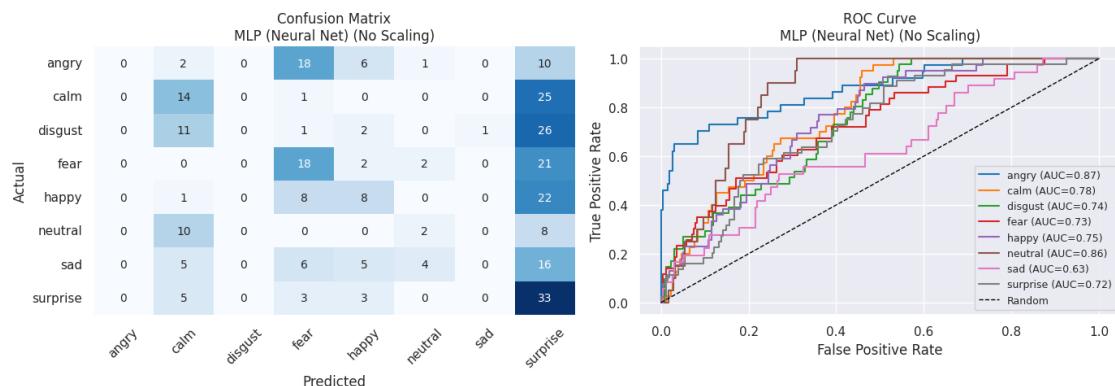
### Training SVM (RBF) (No Scaling)...



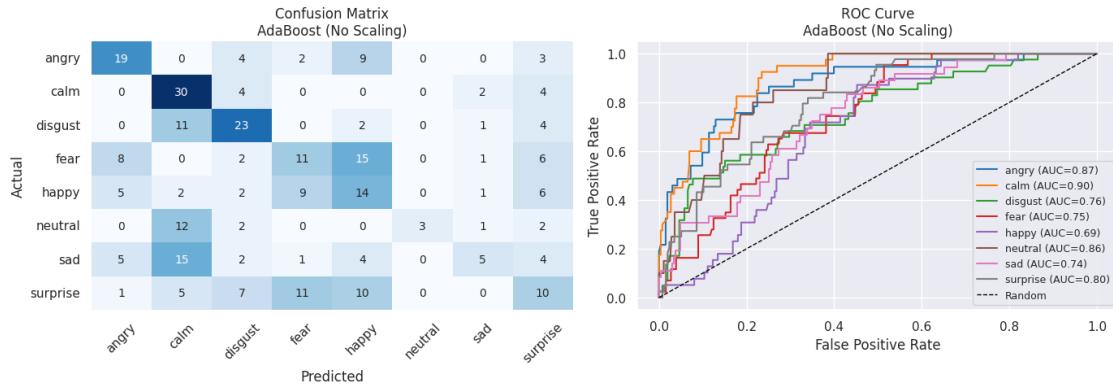
### Training KNN (No Scaling)...



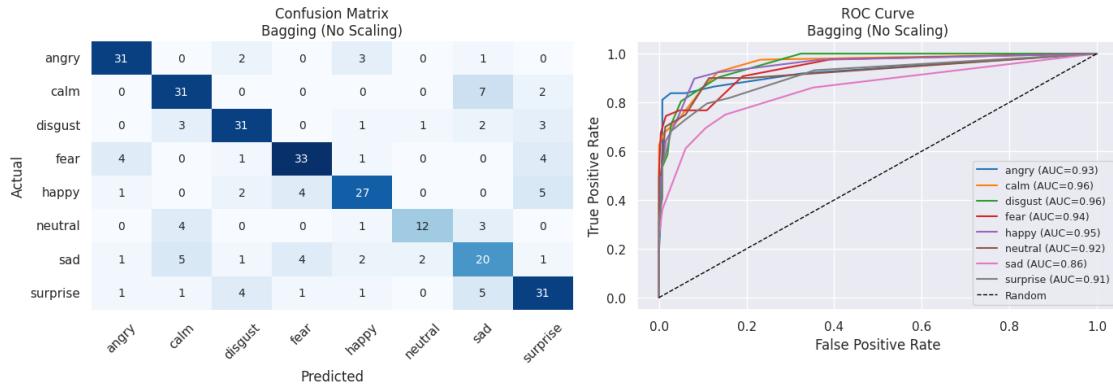
### Training MLP (Neural Net) (No Scaling)...



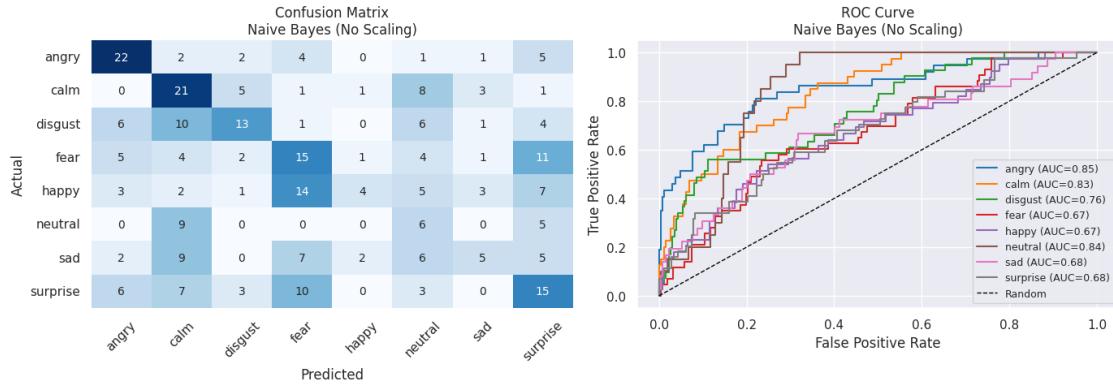
### Training AdaBoost (No Scaling)...



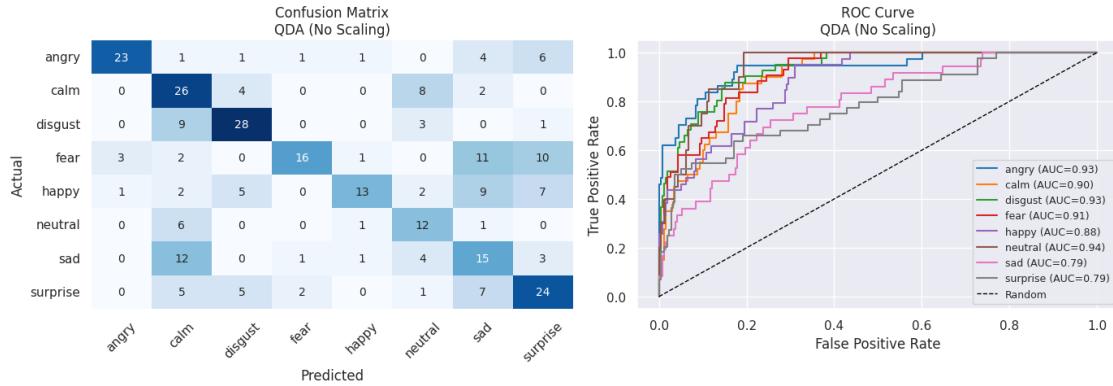
### Training Bagging (No Scaling)...



### Training Naive Bayes (No Scaling)...



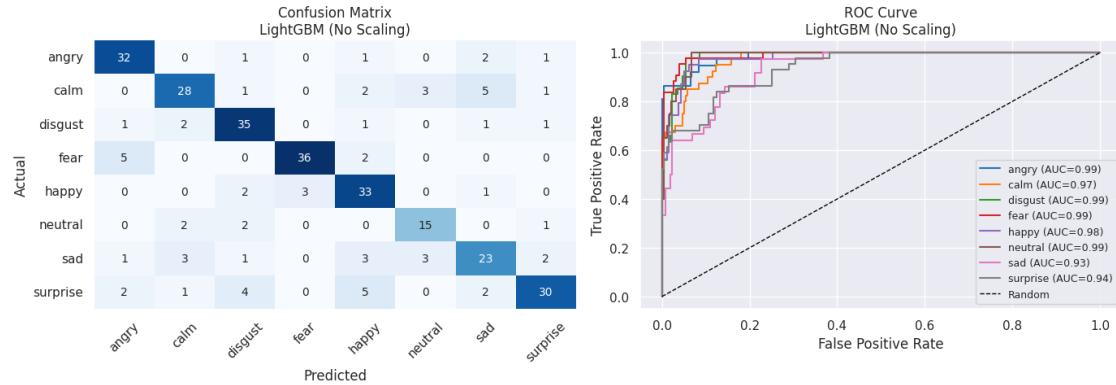
Training QDA (No Scaling)...



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
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[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
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[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,)
```

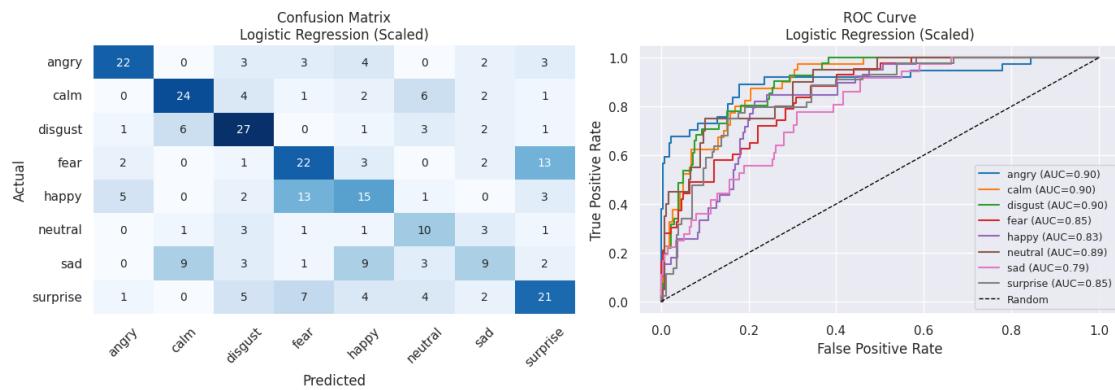
```
[ ]: y_test_scaled.shape
```

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

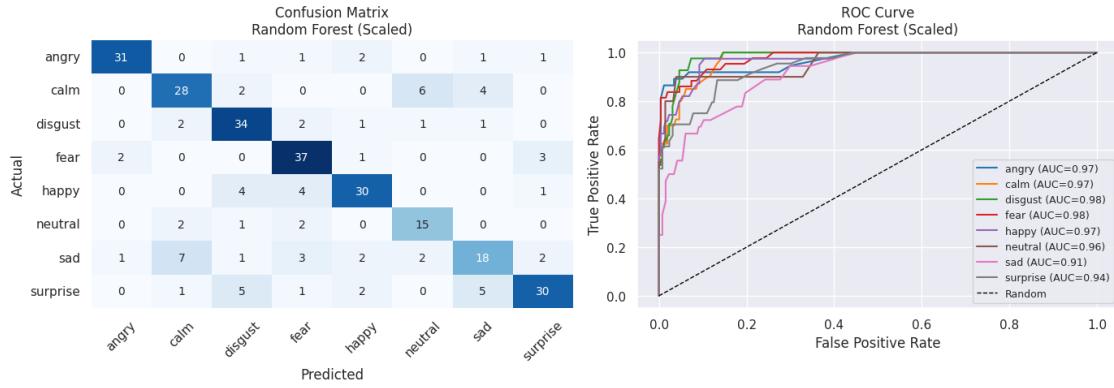
### 9.8.2 Train models and plot results with *StandardScaler*

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

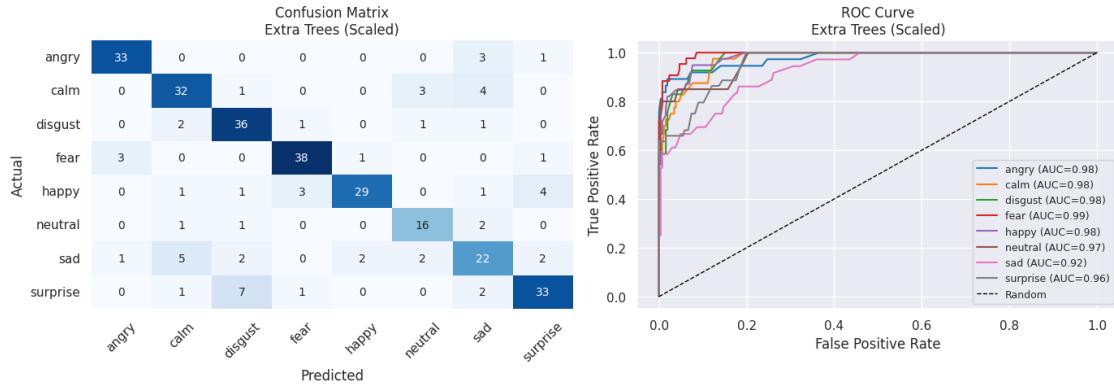
Training Logistic Regression (Scaled)...



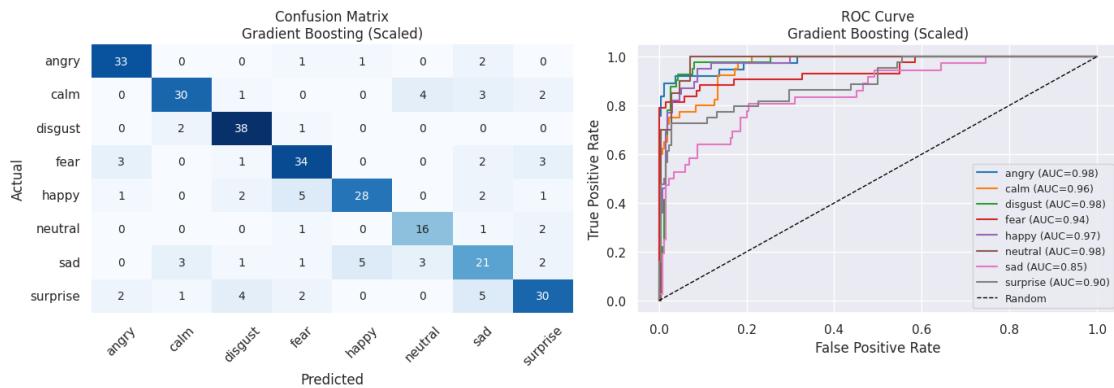
Training Random Forest (Scaled)...



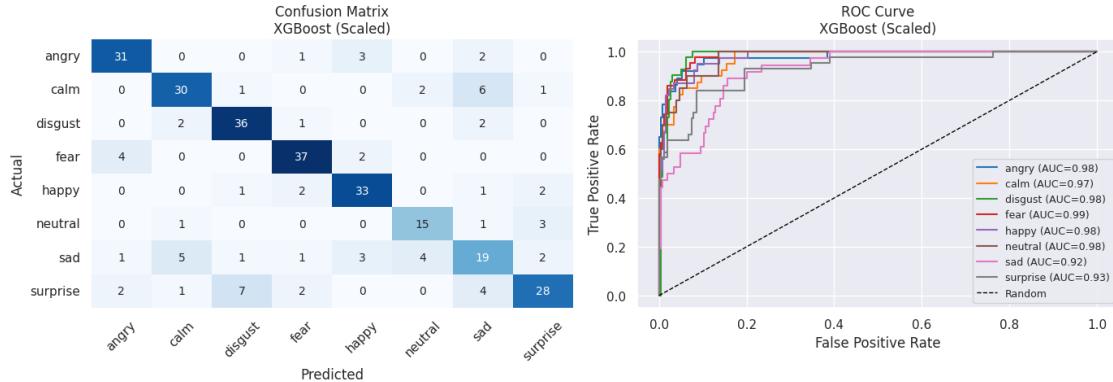
### Training Extra Trees (Scaled)...



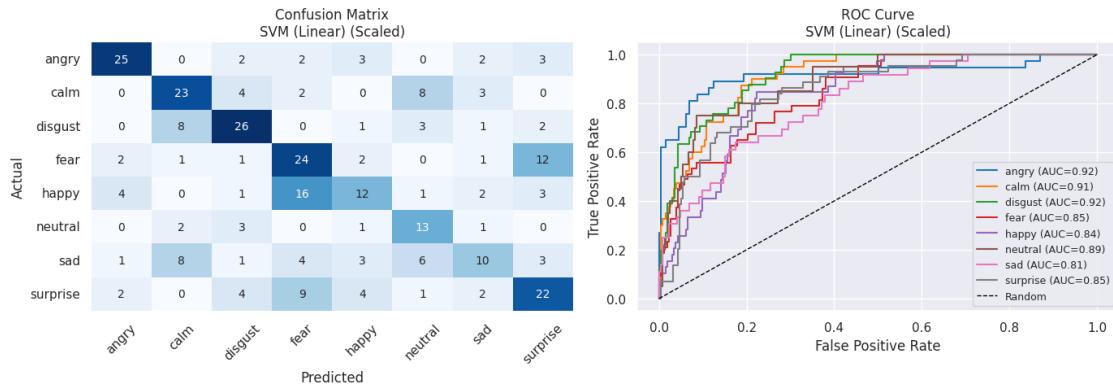
### Training Gradient Boosting (Scaled)...



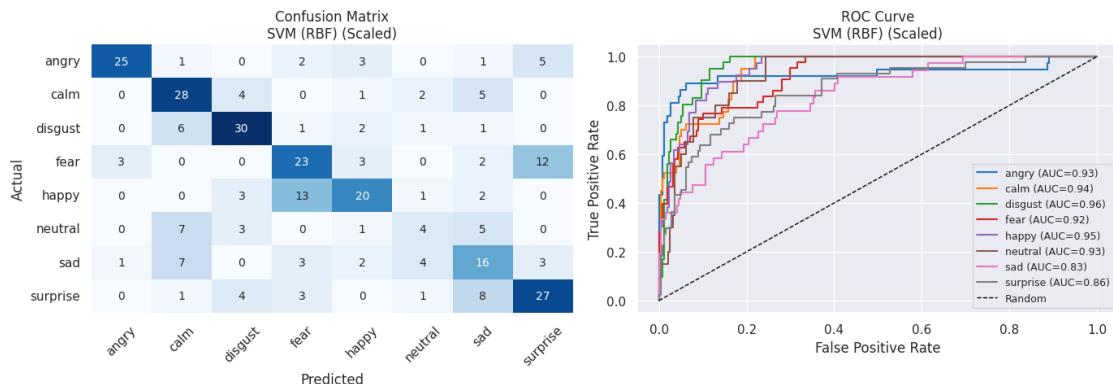
### Training XGBoost (Scaled)...



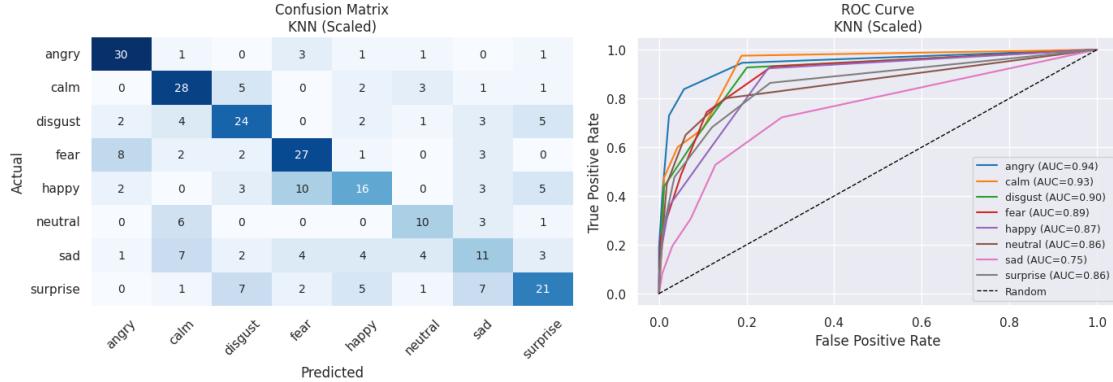
### Training SVM (Linear) (Scaled)...



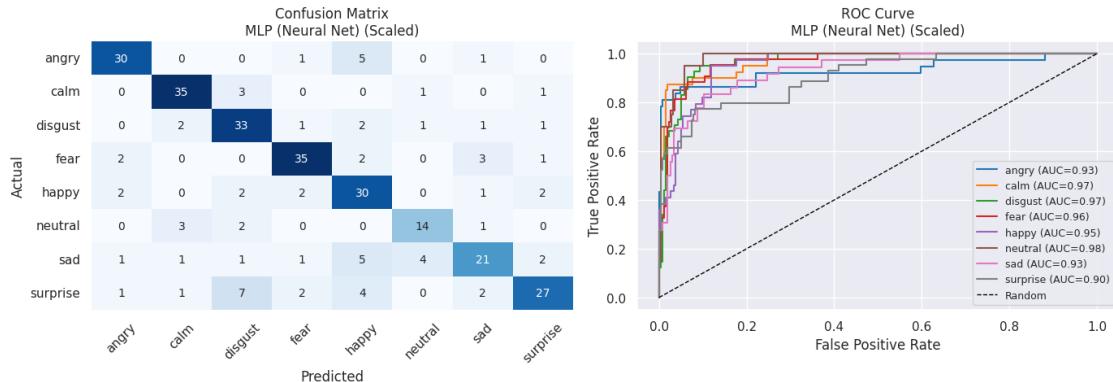
### Training SVM (RBF) (Scaled)...



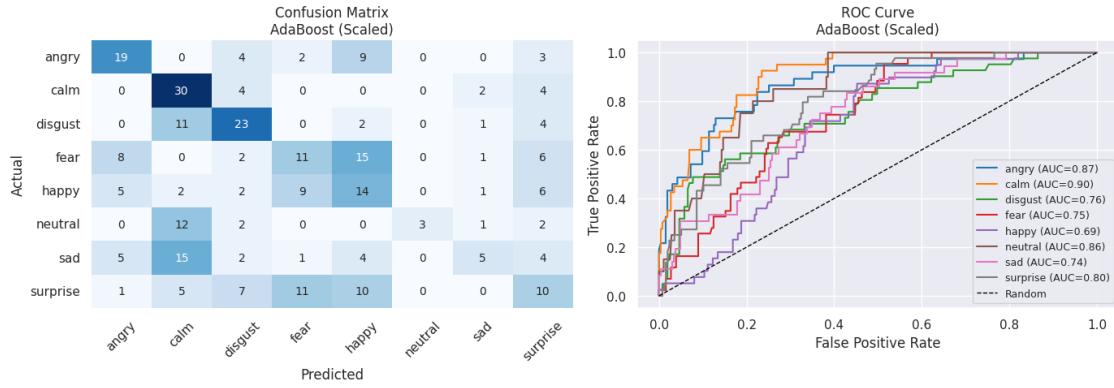
### Training KNN (Scaled)...



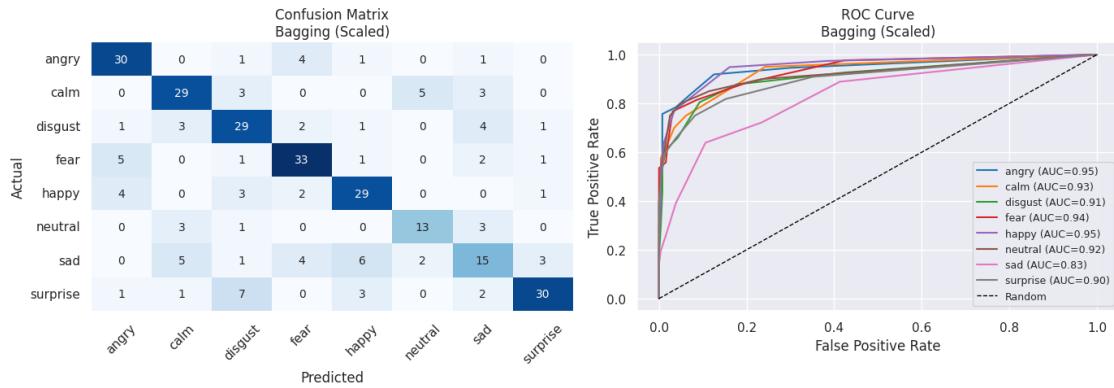
### Training MLP (Neural Net) (Scaled)...



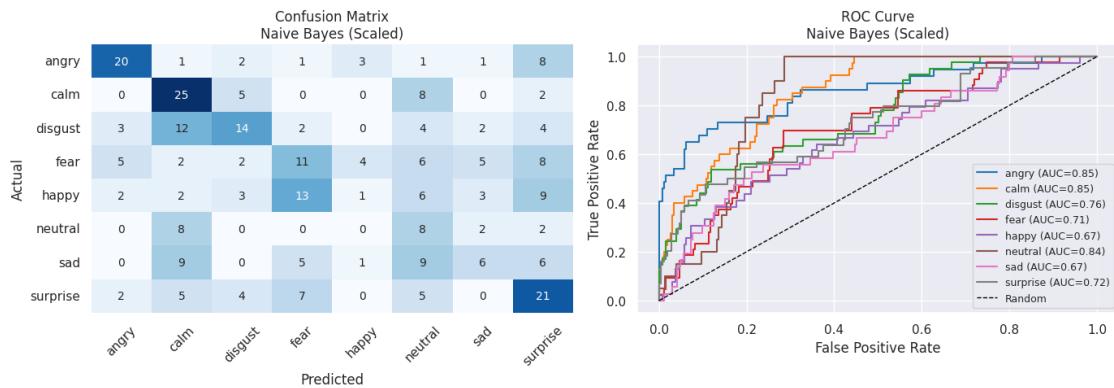
### Training AdaBoost (Scaled)...



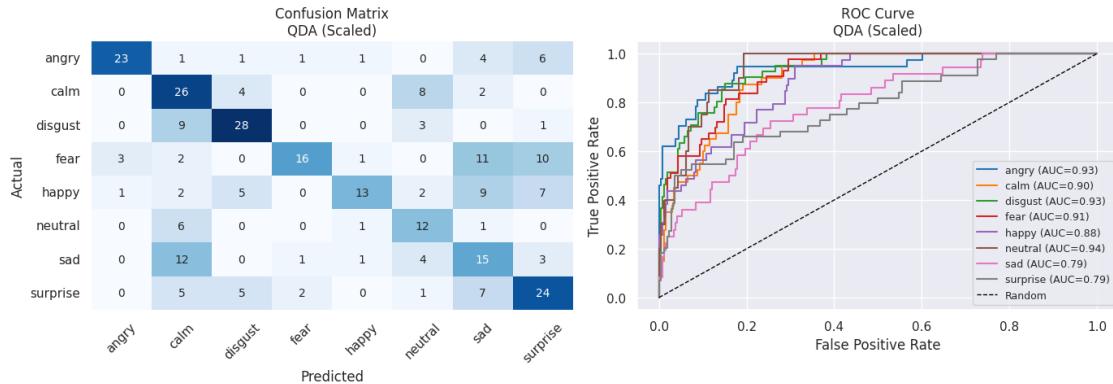
### Training Bagging (Scaled)...



### 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

[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

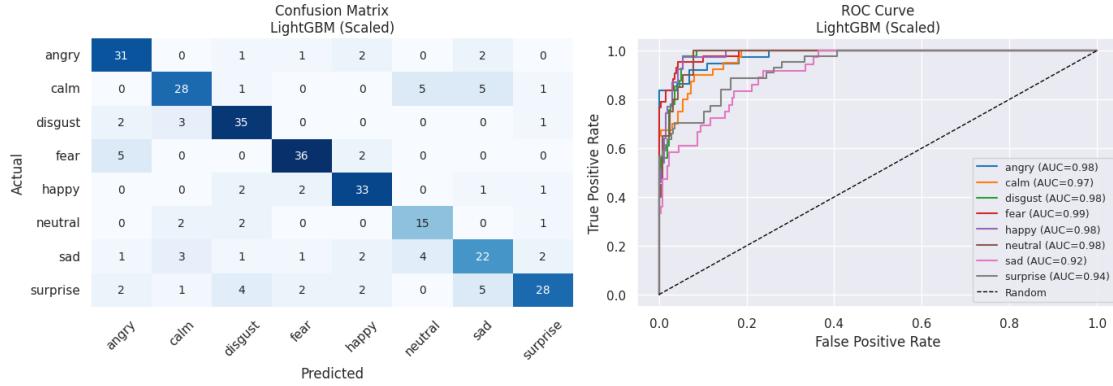
[LightGBM] [Warning] No further splits with positive gain, best gain: -inf

[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)

```

```

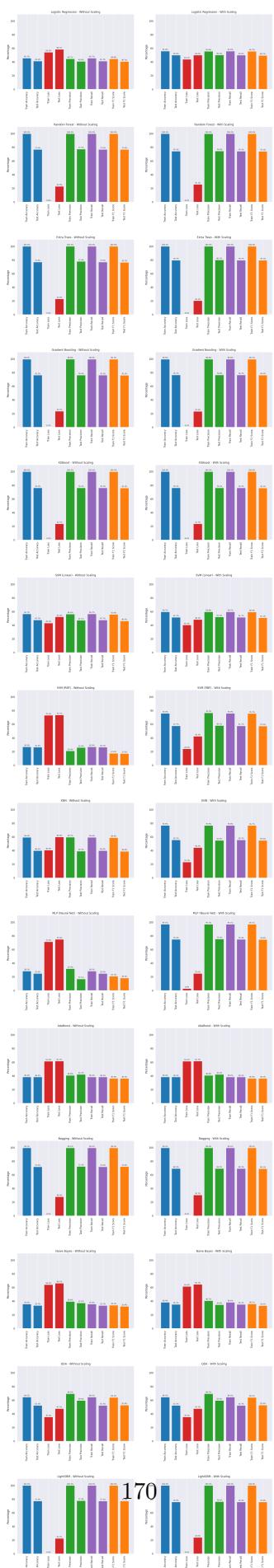
for i, model in enumerate(models):
    for j, scaling in enumerate(['No Scaling', 'Scaled']):
        ax = axes[i, j] if len(models) > 1 else axes[j]
        model_name = f"{model} ({scaling})"
        data = combined_ml_model_results[combined_ml_model_results['Model'] == model_name]

    # 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:
```

```

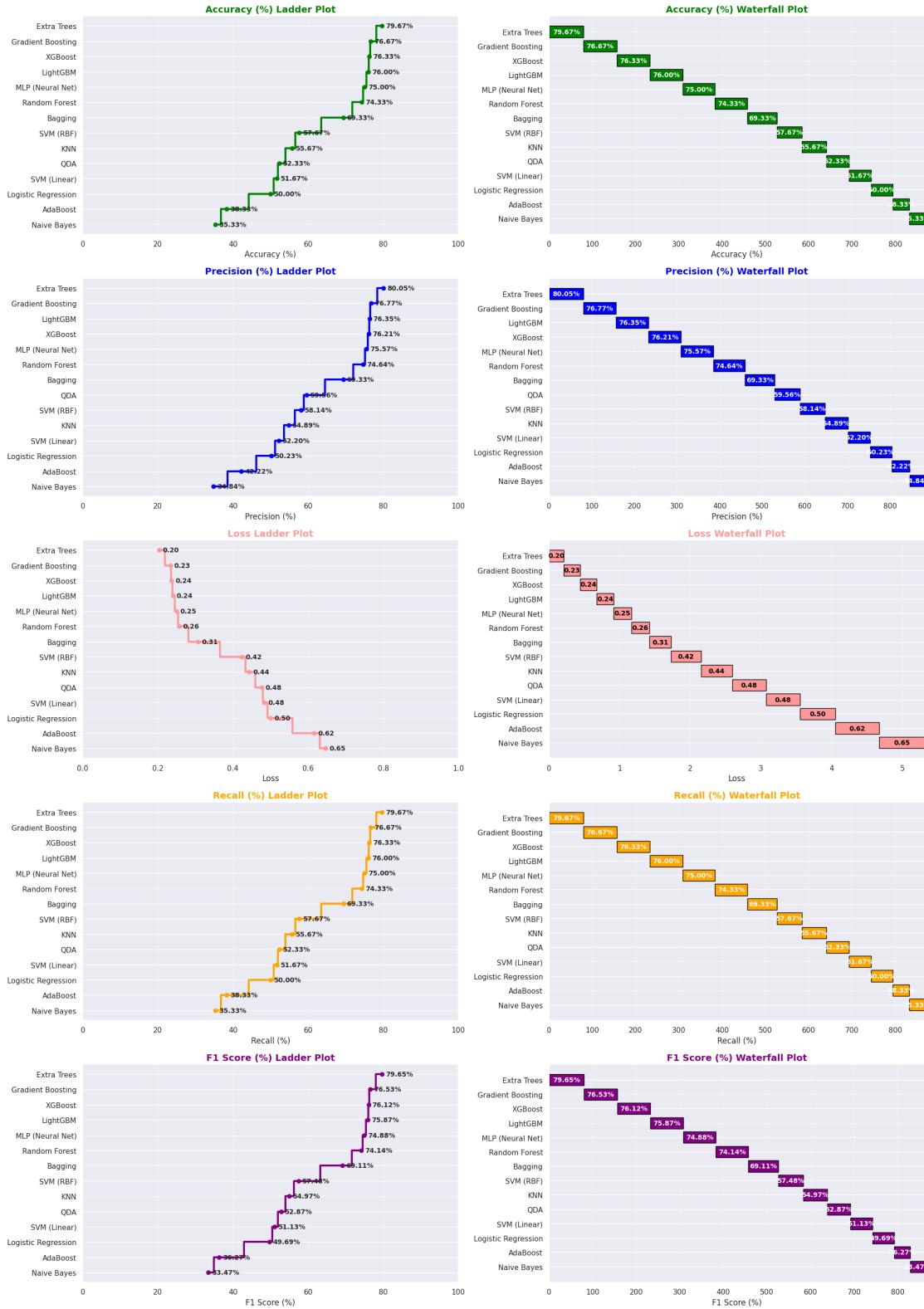
        xlim = (0, 100)
    else:
        display_values = metric_values
        value_fmt = "{:.2f}"
        xlim = (0, 1)

    # --- 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
<b>BasicNN</b>	Dense(128, ReLU) → Dropout(0.3) → Dense(64, ReLU) → Dropout(0.3)	Dropout(0.3) Shallow network	Adam Categorical Crossentropy	50	16 Softmax
<b>DeepNN</b>	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
<b>BN_Activate</b>	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)
```

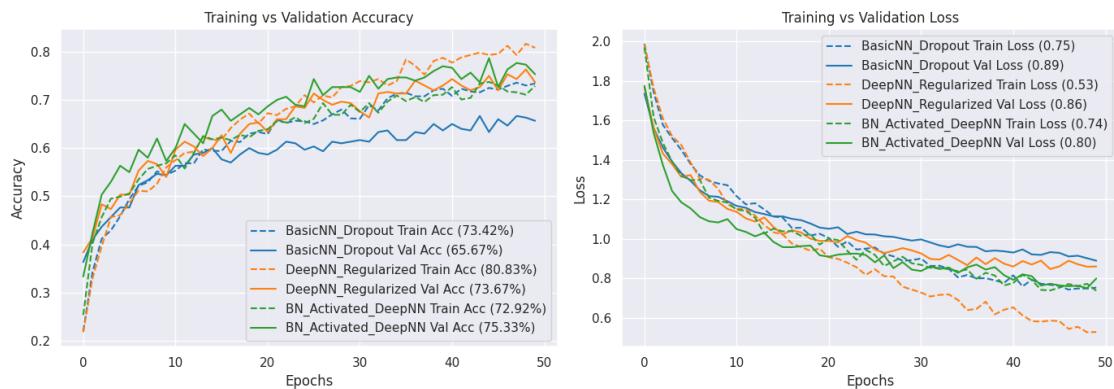
```

# 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

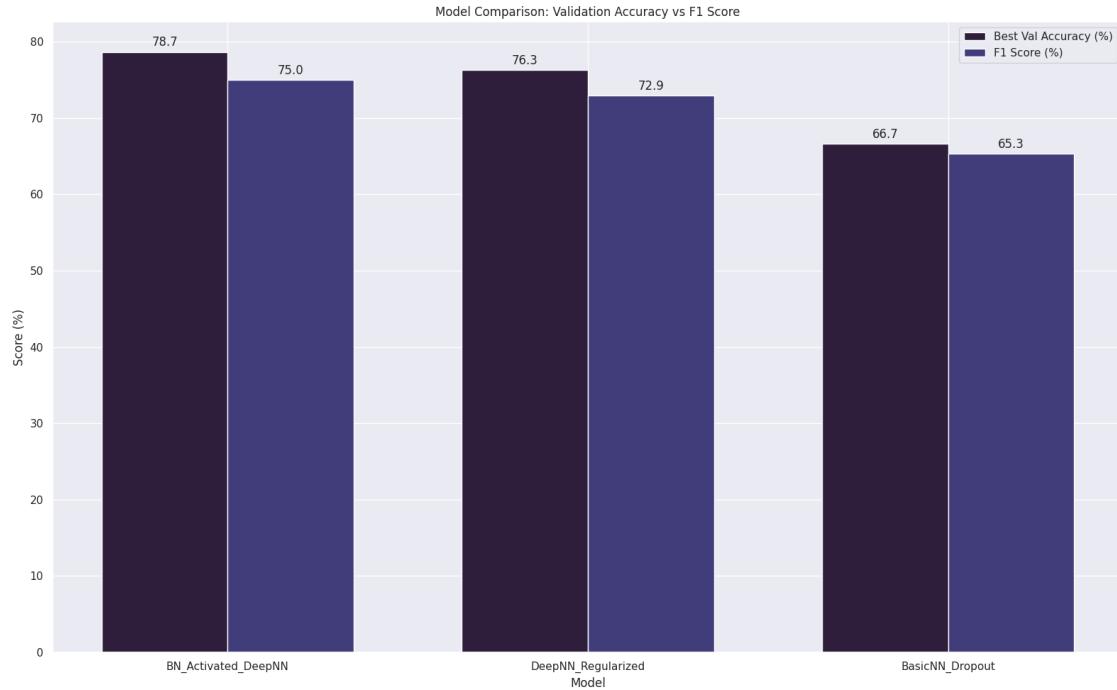
# Plot bars for Validation Accuracy and F1 Score
bar1 = ax1.bar(x - width/2, dl_model_df_results['Best-Validation-Accuracy' ↪
    ↪(%')] , width, label='Best Val Accuracy (%)')
bar2 = ax1.bar(x + width/2, dl_model_df_results['F1-Score (%)'], width, ↪
    ↪label='F1 Score (%)')

# 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 (%)	<b>79.67%</b>	78.67%
F1 Score (%)	<b>79.65%</b>	74.97%
Precision (%)	<b>80.05%</b>	NA
Recall (%)	<b>79.67%</b>	NA
Loss	<b>0.20</b>	<b>0.80</b>
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.
- 

### 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
<b>Use Case</b>	Real-time emotion detection using a chatbot or voice assistant application.
<b>Deployment Type</b>	<b>Real-Time Inference</b> - Immediate return of emotion inference on audio input.
<b>Backend</b>	Python API with <b>FastAPI</b> or <b>Flask</b> to serve the trained model.
<b>Frontend</b>	A web interface or mobile application with live audio input through the use of WebRTC or HTML5.
<b>Hosting</b>	The model hosted on <b>AWS EC2</b> or with <b>Azure App Service docker</b> support.
<b>Latency Target</b>	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

0% [Working]          Get:1 http://security.ubuntu.com/ubuntu jammy-
security InRelease [129 kB]
Get:2 https://cloud.r-project.org/bin/linux/ubuntu jammy-cran40/ InRelease
[3,632 B]
Hit:3 https://developer.download.nvidia.com/compute/cuda/repos/ubuntu2204/x86_64
InRelease
Hit:4 http://archive.ubuntu.com/ubuntu jammy InRelease
Get:5 https://r2u.stat.illinois.edu/ubuntu jammy InRelease [6,555 B]
Get:6 http://archive.ubuntu.com/ubuntu jammy-updates InRelease [128 kB]
Hit:7 https://ppa.launchpadcontent.net/deadsnakes/ppa/ubuntu jammy InRelease
Hit:8 https://ppa.launchpadcontent.net/graphics-drivers/ppa/ubuntu jammy
InRelease
Get:9 http://archive.ubuntu.com/ubuntu jammy-backports InRelease [127 kB]
Hit:10 https://ppa.launchpadcontent.net/ubuntugis/ppa/ubuntu jammy InRelease
Get:11 http://security.ubuntu.com/ubuntu jammy-security/restricted amd64
Packages [4,532 kB]
Get:12 http://security.ubuntu.com/ubuntu jammy-security/universe amd64 Packages
[1,253 kB]
Get:13 http://security.ubuntu.com/ubuntu jammy-security/main amd64 Packages
[3,024 kB]
Get:14 https://r2u.stat.illinois.edu/ubuntu jammy/main amd64 Packages [2,748 kB]
Get:15 https://r2u.stat.illinois.edu/ubuntu jammy/main all Packages [9,053 kB]
Get:16 http://archive.ubuntu.com/ubuntu jammy-updates/restricted amd64 Packages
[4,703 kB]
Get:17 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 Packages [3,340
kB]
Get:18 http://archive.ubuntu.com/ubuntu jammy-updates/universe amd64 Packages
[1,561 kB]
Fetched 30.6 MB in 10s (3,217 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:
  libcmmark-gfm-extensions0.29.0.gfm.3 libcmmark-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:
  libcmark-gfm-extensions0.29.0.gfm.3 libcmark-gfm0.29.0.gfm.3 pandoc
    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.
Get:1 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libcmark-
gfm0.29.0.gfm.3 amd64 0.29.0.gfm.3-3 [115 kB]
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
2.9.2.1-3ubuntu2 [20.3 MB]
Fetched 20.6 MB in 1s (17.4 MB/s)
Selecting previously unselected package libcmark-gfm0.29.0.gfm.3:amd64.
(Reading database ... 126319 files and directories currently installed.)
Preparing to unpack .../libcmark-gfm0.29.0.gfm.3_0.29.0.gfm.3-3_amd64.deb ...
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 ...
Unpacking libcmark-gfm-extensions0.29.0.gfm.3:amd64 (0.29.0.gfm.3-3) ...
Selecting previously unselected package pandoc-data.
Preparing to unpack .../pandoc-data_2.9.2.1-3ubuntu2_all.deb ...
Unpacking pandoc-data (2.9.2.1-3ubuntu2) ...
Selecting previously unselected package pandoc.
Preparing to unpack .../pandoc_2.9.2.1-3ubuntu2_amd64.deb ...
Unpacking pandoc (2.9.2.1-3ubuntu2) ...
Setting up libcmark-gfm0.29.0.gfm.3:amd64 (0.29.0.gfm.3-3) ...
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) ...
Processing triggers for man-db (2.10.2-1) ...
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
/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 libaspell15 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 libgs127
  libgslblas0 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 radiance 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 libdjvuibre-text libdjvuibre21
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.
Get:1 http://archive.ubuntu.com/ubuntu jammy/main amd64 fonts-droid-fallback all
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Get:2 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 gawk amd64
1:5.1.0-1ubuntu0.1 [447 kB]
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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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magick-q16-perl amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [108 kB]
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magick-perl all 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [53.9 kB]
Get:9 http://archive.ubuntu.com/ubuntu jammy-updates/universe amd64
libmagickwand-6.q16-6 amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [328 kB]
Get:10 http://archive.ubuntu.com/ubuntu jammy/main amd64 poppler-data all
0.4.11-1 [2,171 kB]
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amd64 1.7-7build3 [14.3 kB]

```

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0.60.8-4build1 [325 kB]  
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1.28.14 [185 kB]  
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0.60.8-4build1 [87.7 kB]  
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2018.04.16-0-1 [299 kB]  
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20200910-1 [6,367 kB]  
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amd64 9.55.0~dfsg1-0ubuntu5.11 [49.4 kB]  
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2:10.0-15.4 [1,007 kB]  
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20201225-1build1 [397 kB]  
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0.4.17-2 [51.9 kB]  
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all 2.72.0-1 [3,718 B]  
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services amd64 2.72.0-1 [9,982 B]  
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0.3.6 [9,774 B]  
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schemas all 42.0-1ubuntu1 [31.1 kB]

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imagemagick-6.q16 amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [224 kB]  
Get:39 http://archive.ubuntu.com/ubuntu jammy-updates/universe amd64 imagemagick  
amd64 8:6.9.11.60+dfsg-1.3ubuntu0.22.04.5 [14.6 kB]  
Get:40 http://archive.ubuntu.com/ubuntu jammy-updates/main amd64 librsvg2-common  
amd64 2.52.5+dfsg-3ubuntu0.2 [17.7 kB]  
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2.7.1+dfsg-3 [94.4 kB]  
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2.7.1+dfsg-3 [1,000 kB]  
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1.1-2build1 [346 kB]  
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2.10.4-2ubuntu3 [12.1 kB]  
Get:45 http://archive.ubuntu.com/ubuntu jammy/main amd64 libglibmm-2.4-1v5 amd64  
2.66.2-2 [645 kB]  
Get:46 http://archive.ubuntu.com/ubuntu jammy/main amd64 libatkmm-1.6-1v5 amd64  
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amd64 1.12.2-4build3 [45.1 kB]  
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0.0.4-6ubuntu7 [209 kB]  
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0.112-2build1 [65.4 kB]  
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1.9.1-4 [6,114 B]  
Get:52 http://archive.ubuntu.com/ubuntu jammy/main amd64 libgspell-1-2 amd64  
1.9.1-4 [56.5 kB]  
Get:53 http://archive.ubuntu.com/ubuntu jammy/main amd64 libpangomm-1.4-1v5  
amd64 2.46.2-1 [56.1 kB]  
Get:54 http://archive.ubuntu.com/ubuntu jammy/main amd64 libgtkmm-3.0-1v5 amd64  
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  
0.1.7-1build5 [238 kB]  
Get:61 http://archive.ubuntu.com/ubuntu jammy/main amd64 libwpd-0.10-10 amd64  
0.10.3-2build1 [209 kB]  
Get:62 http://archive.ubuntu.com/ubuntu jammy/main amd64 libwpg-0.3-3 amd64  
0.3.3-1build3 [49.9 kB]  
Get:63 http://archive.ubuntu.com/ubuntu jammy/universe amd64 inkscape amd64  
1.1.2-3ubuntu1 [17.8 MB]  
Get:64 http://archive.ubuntu.com/ubuntu jammy/main amd64 libdjvulibre-text all  
3.5.28-2build2 [50.9 kB]  
Get:65 http://archive.ubuntu.com/ubuntu jammy/main amd64 libdjvulibre21 amd64  
3.5.28-2build2 [624 kB]  
Get:66 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libjxr0 amd64  
1.2~git20170615.f752187-5 [174 kB]  
Get:67 http://archive.ubuntu.com/ubuntu jammy/universe amd64 libjxr-tools amd64  
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 5s (12.4 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) ...
```

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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 libaspell15:amd64.  
Preparing to unpack .../11-libaspell15_0.60.8-4build1_amd64.deb ...  
Unpacking libaspell15: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 ...
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Unpacking aspell-en (2018.04.16-0-1) ...
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 ...
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Unpacking libproxy1v5:amd64 (0.4.17-2) ...
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) ...
```

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Selecting previously unselected package libcairoomm-1.0-1v5:amd64.
Preparing to unpack .../46-libcairoomm-1.0-1v5_1.12.2-4build3_amd64.deb ...
Unpacking libcairoomm-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 ...
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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) ...
```

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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 gsffonts (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 libdjvulibre-text (3.5.28-2build2) ...
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 libdjvulibre21: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 libcairoomm-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_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

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) ...
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/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
/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 libzip-0-13 lmodern preview-latex-style rake ruby
  ruby-net-telnet ruby-rubygems ruby-webrick ruby-xmlrpc ruby3.0
  rubygems-integration tiutils 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 libsyntax2 libteckit0 libtexlua53
  libtexluajit2 libwoff1 libzip-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-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-webrick 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]

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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 8s (21.2 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) ...
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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) ...
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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 ...
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Unpacking tipa (2:1.3-21) ...
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:
```

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/var/lib/texmf/dvips/config/config-paper.ps
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_openc1.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
```

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/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 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.
```

[4]: %shell jupyter nbconvert --to pdf '/content/drive/MyDrive/Colab Notebooks/Ravi 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 72 column 1: not an object  
[WARNING] Could not parse YAML metadata at line 84 column 1: not an object  
[WARNING] Could not parse YAML metadata at line 125 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 663508 bytes to notebook.tex  
[NbConvertApp] Building PDF  
[NbConvertApp] Running xelatex 3 times: ['xelatex', 'notebook.tex', '-quiet']  
[NbConvertApp] Running bibtex 1 time: ['bibtex', 'notebook']  
[NbConvertApp] WARNING | bibtex had problems, most likely because there were no citations  
[NbConvertApp] PDF successfully created  
[NbConvertApp] Writing 5044105 bytes to /content/drive/MyDrive/Colab Notebooks/Ravi Teja Kothuru_Final Project AAI-510 Section IN2-Team 14.pdf
```

[4]: