Data_Preprocessing_KaggleAPI

December 11, 2023

To process the data faster, we found that the best way is to call kaggle API and download directly to google colab and unzipped on colab locally.

[ ]:
```
! pip install -q kaggle
```

[ ]:
```
from google.colab import files

files.upload()
```

[ ]:
```
! mkdir ~/.kaggle

! cp kaggle.json ~/.kaggle/
```

[ ]:
```
! chmod 600 ~/.kaggle/kaggle.json
```

[ ]:
```
! kaggle competitions download -c 'asl-signs'
```

```
Downloading asl-signs.zip to /content
100% 37.4G/37.4G [04:49<00:00, 166MB/s]
100% 37.4G/37.4G [04:49<00:00, 139MB/s]
```

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! mkdir asl-signs
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[ ]:
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! unzip asl-signs.zip -d asl-signs
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```

[ ]:
```
!pip install -q pandas pyarrow
!pip install -q mediapipe
```

```
                                        34.5/34.5 MB
```

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46.8 MB/s eta 0:00:00
```

[ ]:
```
!ls
```

```
asl-signs  asl-signs.zip  kaggle.json  sample_data
```

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

```
Mounted at /content/drive
```

[ ]:
```
# Data Folder Directry
main_dir = '/content/asl-signs/'
googledrive_dir = '/content/drive/MyDrive/Colab Notebooks/Data/asl-signs/'
```

During our study of the data and research on the possible model solutions, there is one transformer model approach caught our eye. This transformer model approach was designed by Wijkhuizen, M., in the Kaggle competition (2023). Our project team decided to follow Wijkhuizen, M.'s approach to create a transformer model as one of the models to test for this project. Our goal with this approach is to get a better understanding of the transformer model since Wijkhuizen, M.'s approach is to build a transformer model from scratch and not fine-turn a base model.

Following code are from https://www.kaggle.com/code/markwijkhuizen/gislr-tf-data-processing-transformer-training

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
  ↪gislr-tf-data-processing-transformer-training
import os
import pandas as pd
import numpy as np
import tensorflow as tf
from tqdm import tqdm
from sklearn.model_selection import GroupShuffleSplit
import json
# Constants (adjust these according to your data)
INPUT_SIZE = 64
N_COLS = 100  # Adjust based on your landmark indices
N_DIMS = 3    # Typically x, y, z coordinates
N_ROWS = 543
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
  ↪gislr-tf-data-processing-transformer-training
# Load metadata
metadata_sub_dir = 'train.csv'
metadata_full_file_path = os.path.join(main_dir, metadata_sub_dir)
df_metadata = pd.read_csv(metadata_full_file_path)

# Load sign to index mapping
```

```
signmap_sub_dir = 'sign_to_prediction_index_map.json'
signmap_full_file_path = os.path.join(main_dir, signmap_sub_dir)
with open(signmap_full_file_path, 'r') as file:
    sign_to_index = json.load(file)
df_metadata['sign_index'] = df_metadata['sign'].map(sign_to_index)
```

In Wijkhuizen, M.'s transformer approach, all the data has been reformatted to 4D tensor (Number, Frame, KeyPoint, LandMark), where "Number" is the number of data file which also link to a label y for the meaning of signs. "Frame" is the frame of the video recording; if the frame is larger than 64, it will be downsampled, and if the frame is shorter than 64 frames, then it will be padded (2023). "KeyPoint" is the LandMark keypoint from the Mediapipe tracking result; this approach has limited only 66 key points: Lips has 40 key points, the dominant hand has 21 key points, and the dominant side pose has 5 key points, a total of 66 key points. The "LandMark" is 3 LandMark values of [x, y, z] from MediaPipe tracking. This has significantly reduced the size of data that need to be processed by the model and kept the most possible features that are important to ASL recognition.

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
USE_TYPES = ['left_hand', 'pose', 'right_hand']
START_IDX = 468
LIPS_IDXS0 = np.array([
        61, 185, 40, 39, 37, 0, 267, 269, 270, 409,
        291, 146, 91, 181, 84, 17, 314, 405, 321, 375,
        78, 191, 80, 81, 82, 13, 312, 311, 310, 415,
        95, 88, 178, 87, 14, 317, 402, 318, 324, 308,
    ])
# Landmark indices in original data
LEFT_HAND_IDXS0 = np.arange(468,489)
RIGHT_HAND_IDXS0 = np.arange(522,543)
LEFT_POSE_IDXS0 = np.array([502, 504, 506, 508, 510])
RIGHT_POSE_IDXS0 = np.array([503, 505, 507, 509, 511])
LANDMARK_IDXS_LEFT_DOMINANT0 = np.concatenate((LIPS_IDXS0, LEFT_HAND_IDXS0,␣
 ↪LEFT_POSE_IDXS0))
LANDMARK_IDXS_RIGHT_DOMINANT0 = np.concatenate((LIPS_IDXS0, RIGHT_HAND_IDXS0,␣
 ↪RIGHT_POSE_IDXS0))
HAND_IDXS0 = np.concatenate((LEFT_HAND_IDXS0, RIGHT_HAND_IDXS0), axis=0)
N_COLS = LANDMARK_IDXS_LEFT_DOMINANT0.size
# Landmark indices in processed data
LIPS_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0, LIPS_IDXS0)).
 ↪squeeze()
LEFT_HAND_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0,␣
 ↪LEFT_HAND_IDXS0)).squeeze()
RIGHT_HAND_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0,␣
 ↪RIGHT_HAND_IDXS0)).squeeze()
HAND_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0, HAND_IDXS0)).
 ↪squeeze()
```

```
POSE_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0, LEFT_POSE_IDXS0)).
 ↪squeeze()

print(f'# HAND_IDXS: {len(HAND_IDXS)}, N_COLS: {N_COLS}')
```

```
# HAND_IDXS: 21, N_COLS: 66
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
LIPS_START = 0
LEFT_HAND_START = LIPS_IDXS.size
RIGHT_HAND_START = LEFT_HAND_START + LEFT_HAND_IDXS.size
POSE_START = RIGHT_HAND_START + RIGHT_HAND_IDXS.size

print(f'LIPS_START: {LIPS_START}, LEFT_HAND_START: {LEFT_HAND_START},␣
 ↪RIGHT_HAND_START: {RIGHT_HAND_START}, POSE_START: {POSE_START}')
```

```
LIPS_START: 0, LEFT_HAND_START: 40, RIGHT_HAND_START: 61, POSE_START: 61
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
ROWS_PER_FRAME = 543  # number of landmarks per frame
def load_and_preprocess_data(file_path, preprocess_layer):
    # Load data
    data_columns = ['x', 'y', 'z']
    data = pd.read_parquet(file_path, columns=data_columns)
    n_frames = int(len(data) / ROWS_PER_FRAME)
    data = data.values.reshape(n_frames, ROWS_PER_FRAME, len(data_columns))
    # Apply preprocessing using the PreprocessLayer
    processed_data = preprocess_layer(data.astype(np.float32))

    return processed_data
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# If True, processing data from scratch
# If False, loads preprocessed data
PREPROCESS_DATA = False
TRAIN_MODEL = True
# True: use 10% of participants as validation set
# False: use all data for training -> gives better LB result
USE_VAL = False

N_ROWS = 543
N_DIMS = 3
DIM_NAMES = ['x', 'y', 'z']
SEED = 42
NUM_CLASSES = 250
```

```
IS_INTERACTIVE = True
VERBOSE = 1 if IS_INTERACTIVE else 2

INPUT_SIZE = 64

BATCH_ALL_SIGNS_N = 4
BATCH_SIZE = 256
N_EPOCHS = 100
LR_MAX = 1e-3
N_WARMUP_EPOCHS = 0
WD_RATIO = 0.05
MASK_VAL = 4237
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
class PreprocessLayer(tf.keras.layers.Layer):
    def __init__(self):
        super(PreprocessLayer, self).__init__()
        normalisation_correction = tf.constant([
                    # Add 0.50 to left hand (original right hand) and substract␣
 ↪0.50 of right hand (original left hand)
                    [0] * len(LIPS_IDXS) + [0.50] * len(LEFT_HAND_IDXS) + [0.
 ↪50] * len(POSE_IDXS),
                    # Y coordinates stay intact
                    [0] * len(LANDMARK_IDXS_LEFT_DOMINANT0),
                    # Z coordinates stay intact
                    [0] * len(LANDMARK_IDXS_LEFT_DOMINANT0),
                ],
                dtype=tf.float32,
            )
        self.normalisation_correction = tf.transpose(normalisation_correction,␣
 ↪[1,0])

    def pad_edge(self, t, repeats, side):
        if side == 'LEFT':
            return tf.concat((tf.repeat(t[:1], repeats=repeats, axis=0), t),␣
 ↪axis=0)
        elif side == 'RIGHT':
            return tf.concat((t, tf.repeat(t[-1:], repeats=repeats, axis=0)),␣
 ↪axis=0)

    @tf.function(
        input_signature=(tf.TensorSpec(shape=[None,N_ROWS,N_DIMS], dtype=tf.
 ↪float32),),
    )
    def call(self, data0):
```

```
        # Number of Frames in Video
        N_FRAMES0 = tf.shape(data0)[0]

        # Find dominant hand by comparing summed absolute coordinates
        left_hand_sum = tf.math.reduce_sum(tf.where(tf.math.is_nan(tf.
↪gather(data0, LEFT_HAND_IDXS0, axis=1)), 0, 1))
        right_hand_sum = tf.math.reduce_sum(tf.where(tf.math.is_nan(tf.
↪gather(data0, RIGHT_HAND_IDXS0, axis=1)), 0, 1))
        left_dominant = left_hand_sum >= right_hand_sum

        # Count non NaN Hand values in each frame for the dominant hand
        if left_dominant:
            frames_hands_non_nan_sum = tf.math.reduce_sum(
                    tf.where(tf.math.is_nan(tf.gather(data0, LEFT_HAND_IDXS0,␣
↪axis=1)), 0, 1),
                    axis=[1, 2],
                )
        else:
            frames_hands_non_nan_sum = tf.math.reduce_sum(
                    tf.where(tf.math.is_nan(tf.gather(data0, RIGHT_HAND_IDXS0,␣
↪axis=1)), 0, 1),
                    axis=[1, 2],
                )

        # Find frames indices with coordinates of dominant hand
        non_empty_frames_idxs = tf.where(frames_hands_non_nan_sum > 0)
        non_empty_frames_idxs = tf.squeeze(non_empty_frames_idxs, axis=1)
        # Filter frames
        data = tf.gather(data0, non_empty_frames_idxs, axis=0)

        # Cast Indices in float32 to be compatible with Tensorflow Lite
        non_empty_frames_idxs = tf.cast(non_empty_frames_idxs, tf.float32)
        # Normalize to start with 0
        non_empty_frames_idxs -= tf.reduce_min(non_empty_frames_idxs)

        # Number of Frames in Filtered Video
        N_FRAMES = tf.shape(data)[0]

        # Gather Relevant Landmark Columns
        if left_dominant:
            data = tf.gather(data, LANDMARK_IDXS_LEFT_DOMINANT0, axis=1)
        else:
            data = tf.gather(data, LANDMARK_IDXS_RIGHT_DOMINANT0, axis=1)
            data = (
                    self.normalisation_correction + (
                        (data - self.normalisation_correction) * tf.where(self.
↪normalisation_correction != 0, -1.0, 1.0))
```

```
            )

        # Video fits in INPUT_SIZE
        if N_FRAMES < INPUT_SIZE:
            # Pad With -1 to indicate padding
            non_empty_frames_idxs = tf.pad(non_empty_frames_idxs, [[0,␣
↪INPUT_SIZE-N_FRAMES]], constant_values=-1)
            # Pad Data With Zeros
            data = tf.pad(data, [[0, INPUT_SIZE-N_FRAMES], [0,0], [0,0]],␣
↪constant_values=0)
            # Fill NaN Values With 0
            data = tf.where(tf.math.is_nan(data), 0.0, data)
            return data, non_empty_frames_idxs
        # Video needs to be downsampled to INPUT_SIZE
        else:
            # Repeat
            if N_FRAMES < INPUT_SIZE**2:
                repeats = tf.math.floordiv(INPUT_SIZE * INPUT_SIZE, N_FRAMES0)
                data = tf.repeat(data, repeats=repeats, axis=0)
                non_empty_frames_idxs = tf.repeat(non_empty_frames_idxs,␣
↪repeats=repeats, axis=0)

            # Pad To Multiple Of Input Size
            pool_size = tf.math.floordiv(len(data), INPUT_SIZE)
            if tf.math.mod(len(data), INPUT_SIZE) > 0:
                pool_size += 1

            if pool_size == 1:
                pad_size = (pool_size * INPUT_SIZE) - len(data)
            else:
                pad_size = (pool_size * INPUT_SIZE) % len(data)

            # Pad Start/End with Start/End value
            pad_left = tf.math.floordiv(pad_size, 2) + tf.math.
↪floordiv(INPUT_SIZE, 2)
            pad_right = tf.math.floordiv(pad_size, 2) + tf.math.
↪floordiv(INPUT_SIZE, 2)
            if tf.math.mod(pad_size, 2) > 0:
                pad_right += 1

            # Pad By Concatenating Left/Right Edge Values
            data = self.pad_edge(data, pad_left, 'LEFT')
            data = self.pad_edge(data, pad_right, 'RIGHT')

            # Pad Non Empty Frame Indices
            non_empty_frames_idxs = self.pad_edge(non_empty_frames_idxs,␣
↪pad_left, 'LEFT')
```

```
            non_empty_frames_idxs = self.pad_edge(non_empty_frames_idxs,␣
 ↪pad_right, 'RIGHT')

            # Reshape to Mean Pool
            data = tf.reshape(data, [INPUT_SIZE, -1, N_COLS, N_DIMS])
            non_empty_frames_idxs = tf.reshape(non_empty_frames_idxs,␣
 ↪[INPUT_SIZE, -1])

            # Mean Pool
            data = tf.experimental.numpy.nanmean(data, axis=1)
            non_empty_frames_idxs = tf.experimental.numpy.
 ↪nanmean(non_empty_frames_idxs, axis=1)

            # Fill NaN Values With 0
            data = tf.where(tf.math.is_nan(data), 0.0, data)

            return data, non_empty_frames_idxs

preprocess_layer = PreprocessLayer()
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# Function to preprocess the entire dataset
def preprocess_data(df, main_dir, preprocess_layer):
    X = np.zeros([len(df), INPUT_SIZE, N_COLS, N_DIMS], dtype=np.float32)
    y = np.zeros([len(df)], dtype=np.int32)
    NON_EMPTY_FRAME_IDXS = np.full([len(df), INPUT_SIZE], -1, dtype=np.float32)

    for row_idx, row in tqdm(df.iterrows(), total=len(df)):
        file_path = os.path.join(main_dir, row['path'])
        processed_data, non_empty_frame_idxs =␣
 ↪load_and_preprocess_data(file_path, preprocess_layer)
        X[row_idx] = processed_data
        y[row_idx] = row['sign_index']
        NON_EMPTY_FRAME_IDXS[row_idx] = non_empty_frame_idxs
    # Save processed data
    np.save(os.path.join(googledrive_dir, 'X.npy'), X)
    np.save(os.path.join(googledrive_dir, 'y.npy'), y)
    np.save(os.path.join(googledrive_dir, 'NON_EMPTY_FRAME_IDXS.npy'),␣
 ↪NON_EMPTY_FRAME_IDXS)

    # Optional: Train-Validation Split
    splitter = GroupShuffleSplit(test_size=0.10, n_splits=2, random_state=42)
    train_idxs, val_idxs = next(splitter.split(X, y,␣
 ↪groups=df['participant_id']))
```

```
    # Save Train and Validation Sets
    X_train = X[train_idxs]
    NON_EMPTY_FRAME_IDXS_TRAIN = NON_EMPTY_FRAME_IDXS[train_idxs]
    y_train = y[train_idxs]
    np.save(os.path.join(googledrive_dir, 'X_train.npy'), X[train_idxs])
    np.save(os.path.join(googledrive_dir, 'y_train.npy'), y[train_idxs])
    np.save(os.path.join(googledrive_dir, 'NON_EMPTY_FRAME_IDXS_TRAIN.npy'),␣
 ↪NON_EMPTY_FRAME_IDXS_TRAIN)
    X_val = X[val_idxs]
    NON_EMPTY_FRAME_IDXS_VAL = NON_EMPTY_FRAME_IDXS[val_idxs]
    y_val = y[val_idxs]
    np.save(os.path.join(googledrive_dir, 'X_val.npy'), X[val_idxs])
    np.save(os.path.join(googledrive_dir, 'y_val.npy'), y[val_idxs])
    np.save(os.path.join(googledrive_dir, 'NON_EMPTY_FRAME_IDXS_VAL.npy'),␣
 ↪NON_EMPTY_FRAME_IDXS_VAL)

# Run the preprocessing
preprocess_data(df_metadata, main_dir, preprocess_layer)
```

```
100%|      | 94477/94477 [21:41<00:00, 72.61it/s]
```

Reference:

Wijkhuizen, M. (2023, April 04). GISLR TF Data Processing & Transformer Training. Kaggle. https://www.kaggle.com/code/markwijkhuizen/gislr-tf-data-processing-transformer-training

Model_Training

December 11, 2023

During our study of the data and research on the possible model solutions, there is one transformer model approach caught our eye. This transformer model approach was designed by Wijkhuizen, M., in the Kaggle competition (2023). Our project team decided to follow Wijkhuizen, M.'s approach to create a transformer model as one of the models to test for this project. Our goal with this approach is to get a better understanding of the transformer model since Wijkhuizen, M.'s approach is to build a transformer model from scratch and not fine-turn a base model.

After Modeling.ipynb, we have following result: The overall ASL Transformer designed by Wijkhuizen, M. are shown in APPENDIX 1. After training and valuation, the Model performance is shown in APPENDIX 2. Wijkhuizen, M.'s transformer model has an overall 0.71 F1 score with a weighted precision of 0.74 and a weighted recall of 0.71. It has outperformed any other model types that we tried. Some ASL word predictions perform better than others; for example, airplane, apple, owl etc., have F1 scores higher than 0.90. and other words like kitty, yucky, and suffer under the F1 score lower than 0.40. However, most words' F1 scores are higher than 0.60, so we could use this model for a real-life application with some limitations.

Then we are using full dataset to train the transfomer model again, and save the model weight to model.h5, also the mean and standard divation for lip, hand, and pose will be save to numpy file for loading later:

[ ]:
```
!pip install -q tensorflow-addons
```

```
                                611.8/611.8
kB 8.6 MB/s eta 0:00:00
```

[ ]:
```
import numpy as np
import pandas as pd
import tensorflow as tf
import tensorflow_addons as tfa
import matplotlib.pyplot as plt
import matplotlib as mpl
import seaborn as sn

from tqdm.notebook import tqdm
from sklearn.model_selection import train_test_split, GroupShuffleSplit

import glob
import sys
```

```
import os
import math
import gc
import sys
import sklearn
import scipy
```

```
/usr/local/lib/python3.10/dist-
packages/tensorflow_addons/utils/tfa_eol_msg.py:23: UserWarning:

TensorFlow Addons (TFA) has ended development and introduction of new features.
TFA has entered a minimal maintenance and release mode until a planned end of
life in May 2024.
Please modify downstream libraries to take dependencies from other repositories
in our TensorFlow community (e.g. Keras, Keras-CV, and Keras-NLP).

For more information see: https://github.com/tensorflow/addons/issues/2807

  warnings.warn(
```

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

```
Mounted at /content/drive
```

[ ]:
```
googledrive_dir = '/content/drive/MyDrive/Colab Notebooks/Data/asl-signs/'
```

[ ]:
```
X_train = np.load(f'{googledrive_dir}/X.npy')
y_train = np.load(f'{googledrive_dir}/y.npy')
NON_EMPTY_FRAME_IDXS_TRAIN = np.load(f'{googledrive_dir}/NON_EMPTY_FRAME_IDXS.
 ↪npy')
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# Epsilon value for layer normalisation
LAYER_NORM_EPS = 1e-6

# Dense layer units for landmarks
LIPS_UNITS = 384
HANDS_UNITS = 384
POSE_UNITS = 384
# final embedding and transformer embedding size
UNITS = 512

# Transformer
NUM_BLOCKS = 2
MLP_RATIO = 2
```

```
# Dropout
EMBEDDING_DROPOUT = 0.00
MLP_DROPOUT_RATIO = 0.30
CLASSIFIER_DROPOUT_RATIO = 0.10

# Initiailizers
INIT_HE_UNIFORM = tf.keras.initializers.he_uniform
INIT_GLOROT_UNIFORM = tf.keras.initializers.glorot_uniform
INIT_ZEROS = tf.keras.initializers.constant(0.0)
# Activations
GELU = tf.keras.activations.gelu

print(f'UNITS: {UNITS}')
```

```
UNITS: 512
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# If True, processing data from scratch
# If False, loads preprocessed data
PREPROCESS_DATA = False
TRAIN_MODEL = True
# True: use 10% of participants as validation set
# False: use all data for training -> gives better LB result
USE_VAL = False

N_ROWS = 543
N_DIMS = 3
DIM_NAMES = ['x', 'y', 'z']
SEED = 42
NUM_CLASSES = 250
IS_INTERACTIVE = True
VERBOSE = 1 if IS_INTERACTIVE else 2

INPUT_SIZE = 64

BATCH_ALL_SIGNS_N = 4
BATCH_SIZE = 256
N_EPOCHS = 100
LR_MAX = 1e-3
N_WARMUP_EPOCHS = 0
WD_RATIO = 0.05
MASK_VAL = 4237
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
USE_TYPES = ['left_hand', 'pose', 'right_hand']
```

```
START_IDX = 468
LIPS_IDXS0 = np.array([
        61, 185, 40, 39, 37, 0, 267, 269, 270, 409,
        291, 146, 91, 181, 84, 17, 314, 405, 321, 375,
        78, 191, 80, 81, 82, 13, 312, 311, 310, 415,
        95, 88, 178, 87, 14, 317, 402, 318, 324, 308,
    ])
# Landmark indices in original data
LEFT_HAND_IDXS0 = np.arange(468,489)
RIGHT_HAND_IDXS0 = np.arange(522,543)
LEFT_POSE_IDXS0 = np.array([502, 504, 506, 508, 510])
RIGHT_POSE_IDXS0 = np.array([503, 505, 507, 509, 511])
LANDMARK_IDXS_LEFT_DOMINANT0 = np.concatenate((LIPS_IDXS0, LEFT_HAND_IDXS0,␣
 ↪LEFT_POSE_IDXS0))
LANDMARK_IDXS_RIGHT_DOMINANT0 = np.concatenate((LIPS_IDXS0, RIGHT_HAND_IDXS0,␣
 ↪RIGHT_POSE_IDXS0))
HAND_IDXS0 = np.concatenate((LEFT_HAND_IDXS0, RIGHT_HAND_IDXS0), axis=0)
N_COLS = LANDMARK_IDXS_LEFT_DOMINANT0.size
# Landmark indices in processed data
LIPS_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0, LIPS_IDXS0)).
 ↪squeeze()
LEFT_HAND_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0,␣
 ↪LEFT_HAND_IDXS0)).squeeze()
RIGHT_HAND_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0,␣
 ↪RIGHT_HAND_IDXS0)).squeeze()
HAND_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0, HAND_IDXS0)).
 ↪squeeze()
POSE_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0, LEFT_POSE_IDXS0)).
 ↪squeeze()

print(f'# HAND_IDXS: {len(HAND_IDXS)}, N_COLS: {N_COLS}')
```

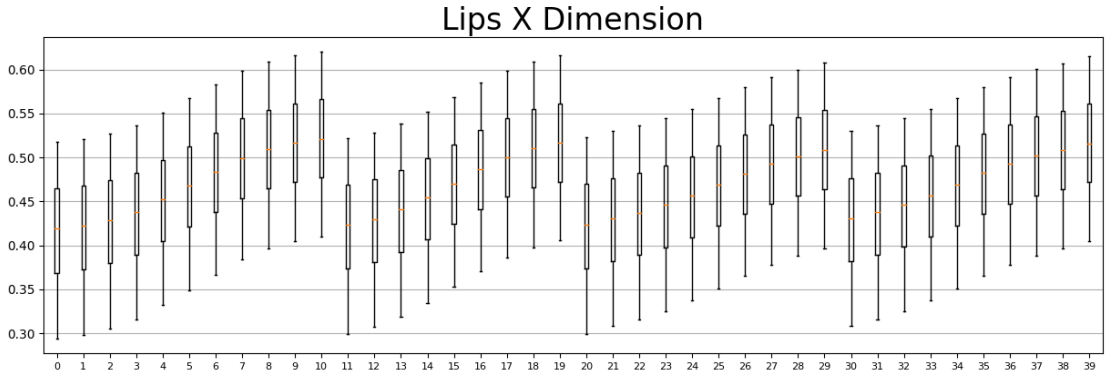
```
# HAND_IDXS: 21, N_COLS: 66
```

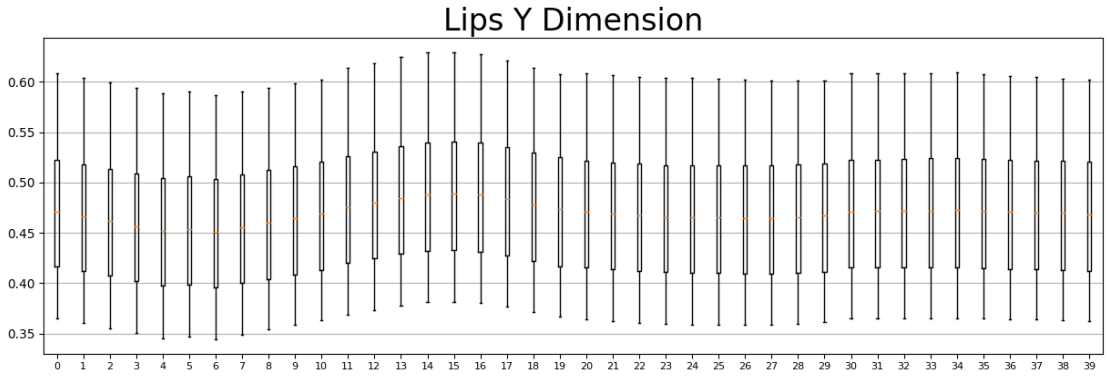
[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
LIPS_START = 0
LEFT_HAND_START = LIPS_IDXS.size
RIGHT_HAND_START = LEFT_HAND_START + LEFT_HAND_IDXS.size
POSE_START = RIGHT_HAND_START + RIGHT_HAND_IDXS.size

print(f'LIPS_START: {LIPS_START}, LEFT_HAND_START: {LEFT_HAND_START},␣
 ↪RIGHT_HAND_START: {RIGHT_HAND_START}, POSE_START: {POSE_START}')
```

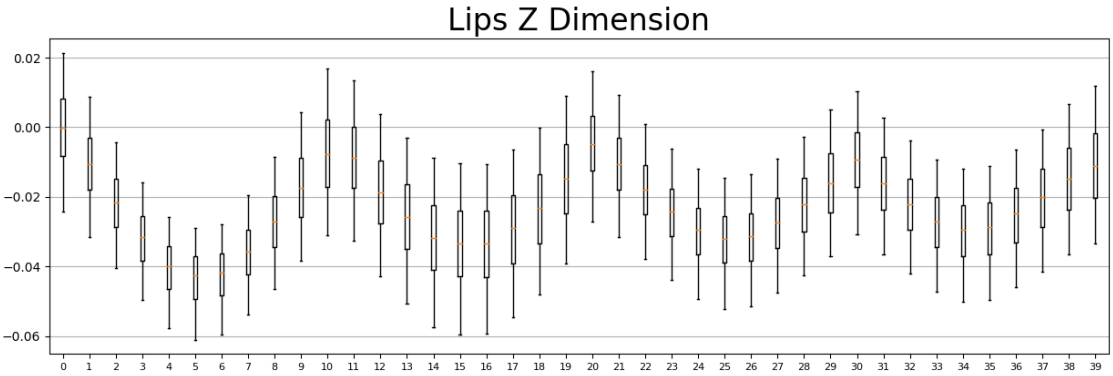
```
LIPS_START: 0, LEFT_HAND_START: 40, RIGHT_HAND_START: 61, POSE_START: 61
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
def get_lips_mean_std():
    # LIPS
    LIPS_MEAN_X = np.zeros([LIPS_IDXS.size], dtype=np.float32)
    LIPS_MEAN_Y = np.zeros([LIPS_IDXS.size], dtype=np.float32)
    LIPS_STD_X = np.zeros([LIPS_IDXS.size], dtype=np.float32)
    LIPS_STD_Y = np.zeros([LIPS_IDXS.size], dtype=np.float32)

    fig, axes = plt.subplots(3, 1, figsize=(15, N_DIMS*6))

    for col, ll in enumerate(tqdm( np.transpose(X_train[:,:,LIPS_IDXS],␣
 ↪[2,3,0,1]).reshape([LIPS_IDXS.size, N_DIMS, -1]) )):
        for dim, l in enumerate(ll):
            v = l[np.nonzero(l)]
            if dim == 0: # X
                LIPS_MEAN_X[col] = v.mean()
                LIPS_STD_X[col] = v.std()
            if dim == 1: # Y
                LIPS_MEAN_Y[col] = v.mean()
                LIPS_STD_Y[col] = v.std()

            axes[dim].boxplot(v, notch=False, showfliers=False,␣
 ↪positions=[col], whis=[5,95])

    for ax, dim_name in zip(axes, DIM_NAMES):
        ax.set_title(f'Lips {dim_name.upper()} Dimension', size=24)
        ax.tick_params(axis='x', labelsize=8)
        ax.grid(axis='y')

    plt.subplots_adjust(hspace=0.50)
    plt.show()

    LIPS_MEAN = np.array([LIPS_MEAN_X, LIPS_MEAN_Y]).T
    LIPS_STD = np.array([LIPS_STD_X, LIPS_STD_Y]).T

    return LIPS_MEAN, LIPS_STD

LIPS_MEAN, LIPS_STD = get_lips_mean_std()
```

```
  0%|          | 0/40 [00:00<?, ?it/s]
```



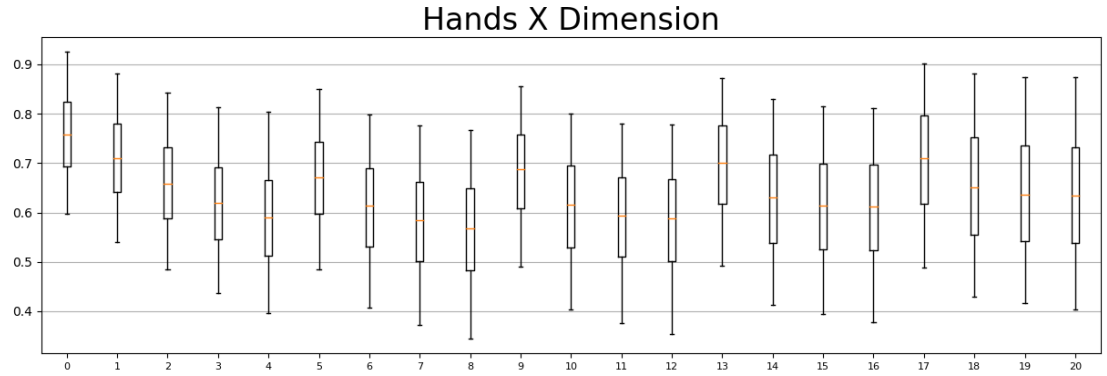


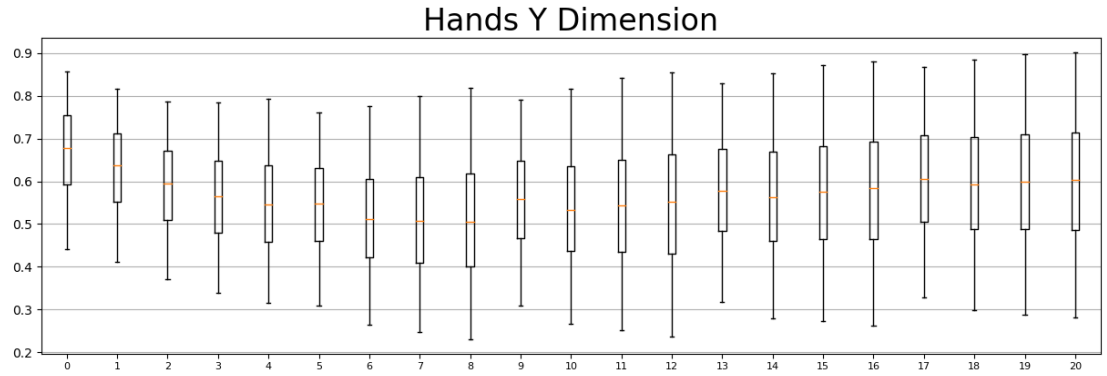


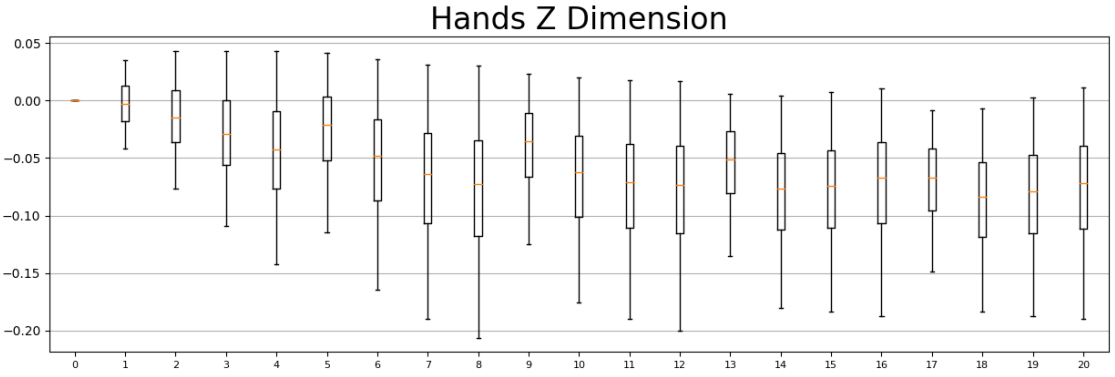
[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
  ↪gislr-tf-data-processing-transformer-training
def get_left_right_hand_mean_std():
    # LEFT HAND
    LEFT_HANDS_MEAN_X = np.zeros([LEFT_HAND_IDXS.size], dtype=np.float32)
    LEFT_HANDS_MEAN_Y = np.zeros([LEFT_HAND_IDXS.size], dtype=np.float32)
    LEFT_HANDS_STD_X = np.zeros([LEFT_HAND_IDXS.size], dtype=np.float32)
```

```
    LEFT_HANDS_STD_Y = np.zeros([LEFT_HAND_IDXS.size], dtype=np.float32)

    fig, axes = plt.subplots(3, 1, figsize=(15, N_DIMS*6))

    for col, ll in enumerate(tqdm( np.transpose(X_train[:,:,LEFT_HAND_IDXS],␣
 ↪[2,3,0,1]).reshape([LEFT_HAND_IDXS.size, N_DIMS, -1]) )):
        for dim, l in enumerate(ll):
            v = l[np.nonzero(l)]
            if dim == 0: # X
                LEFT_HANDS_MEAN_X[col] = v.mean()
                LEFT_HANDS_STD_X[col] = v.std()
            if dim == 1: # Y
                LEFT_HANDS_MEAN_Y[col] = v.mean()
                LEFT_HANDS_STD_Y[col] = v.std()
            # Plot
            axes[dim].boxplot(v, notch=False, showfliers=False,␣
 ↪positions=[col], whis=[5,95])

    for ax, dim_name in zip(axes, DIM_NAMES):
        ax.set_title(f'Hands {dim_name.upper()} Dimension', size=24)
        ax.tick_params(axis='x', labelsize=8)
        ax.grid(axis='y')

    plt.subplots_adjust(hspace=0.50)
    plt.show()

    LEFT_HANDS_MEAN = np.array([LEFT_HANDS_MEAN_X, LEFT_HANDS_MEAN_Y]).T
    LEFT_HANDS_STD = np.array([LEFT_HANDS_STD_X, LEFT_HANDS_STD_Y]).T

    return LEFT_HANDS_MEAN, LEFT_HANDS_STD

LEFT_HANDS_MEAN, LEFT_HANDS_STD = get_left_right_hand_mean_std()
```

```
  0%|          | 0/21 [00:00<?, ?it/s]
```



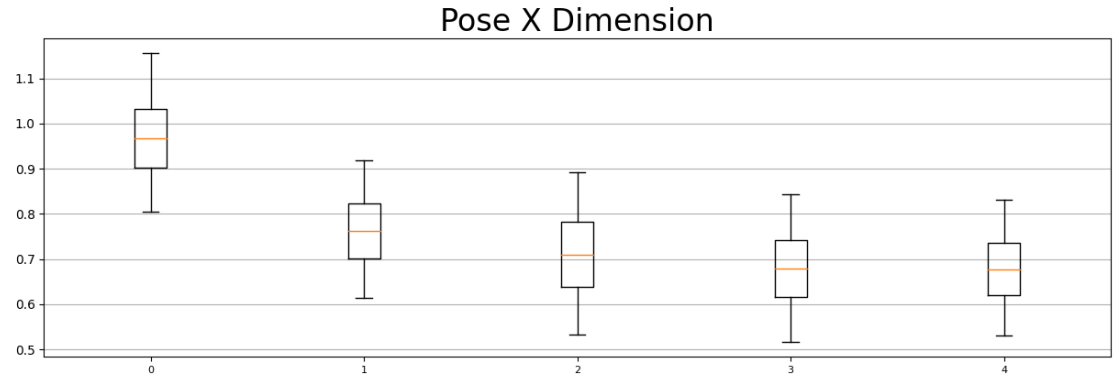


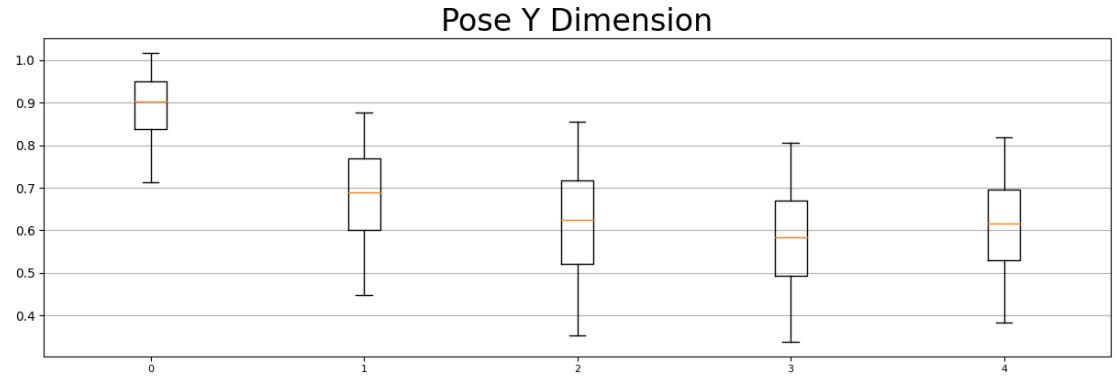


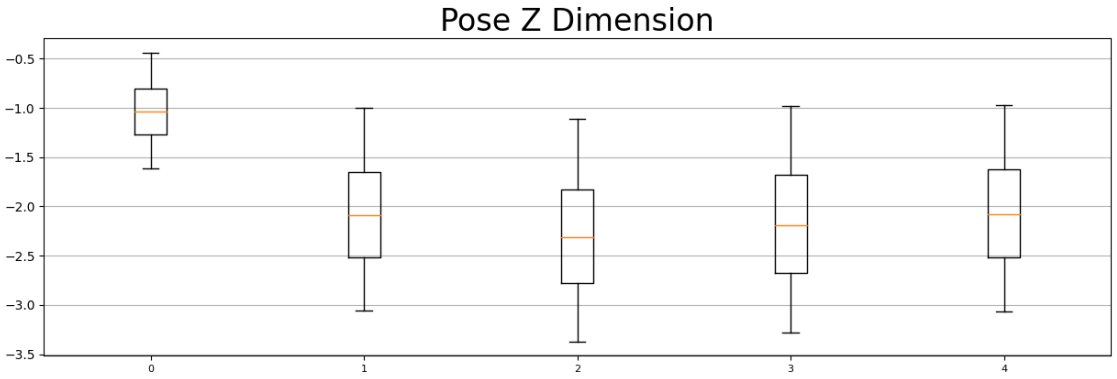
[ ]:
```python
# Code From https://www.kaggle.com/code/markwijkhuizen/
  ↪gislr-tf-data-processing-transformer-training
def get_pose_mean_std():
    # POSE
    POSE_MEAN_X = np.zeros([POSE_IDXS.size], dtype=np.float32)
    POSE_MEAN_Y = np.zeros([POSE_IDXS.size], dtype=np.float32)
    POSE_STD_X = np.zeros([POSE_IDXS.size], dtype=np.float32)
```

```
    POSE_STD_Y = np.zeros([POSE_IDXS.size], dtype=np.float32)

    fig, axes = plt.subplots(3, 1, figsize=(15, N_DIMS*6))

    for col, ll in enumerate(tqdm( np.transpose(X_train[:,:,POSE_IDXS],␣
 ↪[2,3,0,1]).reshape([POSE_IDXS.size, N_DIMS, -1]) )):
        for dim, l in enumerate(ll):
            v = l[np.nonzero(l)]
            if dim == 0: # X
                POSE_MEAN_X[col] = v.mean()
                POSE_STD_X[col] = v.std()
            if dim == 1: # Y
                POSE_MEAN_Y[col] = v.mean()
                POSE_STD_Y[col] = v.std()

            axes[dim].boxplot(v, notch=False, showfliers=False,␣
 ↪positions=[col], whis=[5,95])

    for ax, dim_name in zip(axes, DIM_NAMES):
        ax.set_title(f'Pose {dim_name.upper()} Dimension', size=24)
        ax.tick_params(axis='x', labelsize=8)
        ax.grid(axis='y')

    plt.subplots_adjust(hspace=0.50)
    plt.show()

    POSE_MEAN = np.array([POSE_MEAN_X, POSE_MEAN_Y]).T
    POSE_STD = np.array([POSE_STD_X, POSE_STD_Y]).T

    return POSE_MEAN, POSE_STD

POSE_MEAN, POSE_STD = get_pose_mean_std()
```

```
  0%|          | 0/5 [00:00<?, ?it/s]
```







[ ]:
```
LIPS_STD
```

[ ]:
```
array([[0.06913371, 0.0749447 ],
       [0.06869563, 0.07505549],
       [0.06836782, 0.07519231],
       [0.06812248, 0.07535139],
       [0.06790033, 0.07548924],
```

```
       [0.06740177, 0.07569747],
       [0.06690664, 0.07540744],
       [0.06630632, 0.0751383 ],
       [0.06579747, 0.07488327],
       [0.06536146, 0.07465134],
       [0.06490868, 0.07446797],
       [0.0686974 , 0.07510085],
       [0.06826583, 0.07542164],
       [0.06773155, 0.07593741],
       [0.06713565, 0.07637213],
       [0.06652237, 0.07647745],
       [0.06590941, 0.07628901],
       [0.06545945, 0.07577442],
       [0.06515191, 0.07514609],
       [0.06499287, 0.0747105 ],
       [0.06892715, 0.0749959 ],
       [0.06840112, 0.07515378],
       [0.0680631 , 0.07531367],
       [0.06770497, 0.07549456],
       [0.0673436 , 0.07565831],
       [0.06693598, 0.07573235],
       [0.06640731, 0.07556409],
       [0.06595178, 0.07529225],
       [0.06554479, 0.07501528],
       [0.06529062, 0.07478278],
       [0.0683827 , 0.07500488],
       [0.0680342 , 0.07509418],
       [0.06765123, 0.07527245],
       [0.06726003, 0.07546542],
       [0.06684113, 0.07556838],
       [0.06633036, 0.07539269],
       [0.06588241, 0.07511063],
       [0.06549872, 0.07483311],
       [0.06523801, 0.07465854],
       [0.06498756, 0.07455516]], dtype=float32)
```

[ ]:
```
np.save(os.path.join(googledrive_dir, 'LIPS_MEAN.npy'), LIPS_MEAN)
np.save(os.path.join(googledrive_dir, 'LIPS_STD.npy'), LIPS_STD)
np.save(os.path.join(googledrive_dir, 'LEFT_HANDS_MEAN.npy'), LEFT_HANDS_MEAN)
np.save(os.path.join(googledrive_dir, 'LEFT_HANDS_STD.npy'), LEFT_HANDS_STD)
np.save(os.path.join(googledrive_dir, 'POSE_MEAN.npy'), POSE_MEAN)
np.save(os.path.join(googledrive_dir, 'POSE_STD.npy'), POSE_STD)
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# based on: https://stackoverflow.com/questions/67342988/
 ↪verifying-the-implementation-of-multihead-attention-in-transformer
```

```
# replaced softmax with softmax layer to support masked softmax
def scaled_dot_product(q,k,v, softmax, attention_mask):
    #calculates Q . K(transpose)
    qkt = tf.matmul(q,k,transpose_b=True)
    #caculates scaling factor
    dk = tf.math.sqrt(tf.cast(q.shape[-1],dtype=tf.float32))
    scaled_qkt = qkt/dk
    softmax = softmax(scaled_qkt, mask=attention_mask)

    z = tf.matmul(softmax,v)
    #shape: (m,Tx,depth), same shape as q,k,v
    return z

class MultiHeadAttention(tf.keras.layers.Layer):
    def __init__(self,d_model,num_of_heads):
        super(MultiHeadAttention,self).__init__()
        self.d_model = d_model
        self.num_of_heads = num_of_heads
        self.depth = d_model//num_of_heads
        self.wq = [tf.keras.layers.Dense(self.depth) for i in␣
 ↪range(num_of_heads)]
        self.wk = [tf.keras.layers.Dense(self.depth) for i in␣
 ↪range(num_of_heads)]
        self.wv = [tf.keras.layers.Dense(self.depth) for i in␣
 ↪range(num_of_heads)]
        self.wo = tf.keras.layers.Dense(d_model)
        self.softmax = tf.keras.layers.Softmax()

    def call(self,x, attention_mask):

        multi_attn = []
        for i in range(self.num_of_heads):
            Q = self.wq[i](x)
            K = self.wk[i](x)
            V = self.wv[i](x)
            multi_attn.append(scaled_dot_product(Q,K,V, self.softmax,␣
 ↪attention_mask))

        multi_head = tf.concat(multi_attn,axis=-1)
        multi_head_attention = self.wo(multi_head)
        return multi_head_attention
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# Full Transformer
class Transformer(tf.keras.Model):
    def __init__(self, num_blocks):
```

```
        super(Transformer, self).__init__(name='transformer')
        self.num_blocks = num_blocks

    def build(self, input_shape):
        self.ln_1s = []
        self.mhas = []
        self.ln_2s = []
        self.mlps = []
        # Make Transformer Blocks
        for i in range(self.num_blocks):
            # Multi Head Attention
            self.mhas.append(MultiHeadAttention(UNITS, 8))
            # Multi Layer Perception
            self.mlps.append(tf.keras.Sequential([
                tf.keras.layers.Dense(UNITS * MLP_RATIO, activation=GELU,␣
↪kernel_initializer=INIT_GLOROT_UNIFORM),
                tf.keras.layers.Dropout(MLP_DROPOUT_RATIO),
                tf.keras.layers.Dense(UNITS,␣
↪kernel_initializer=INIT_HE_UNIFORM),
            ]))

    def call(self, x, attention_mask):
        # Iterate input over transformer blocks
        for mha, mlp in zip(self.mhas, self.mlps):
            x = x + mha(x, attention_mask)
            x = x + mlp(x)

        return x
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
↪gislr-tf-data-processing-transformer-training
class LandmarkEmbedding(tf.keras.Model):
    def __init__(self, units, name):
        super(LandmarkEmbedding, self).__init__(name=f'{name}_embedding')
        self.units = units

    def build(self, input_shape):
        # Embedding for missing landmark in frame, initizlied with zeros
        self.empty_embedding = self.add_weight(
            name=f'{self.name}_empty_embedding',
            shape=[self.units],
            initializer=INIT_ZEROS,
        )
        # Embedding
        self.dense = tf.keras.Sequential([
            tf.keras.layers.Dense(self.units, name=f'{self.name}_dense_1',␣
↪use_bias=False, kernel_initializer=INIT_GLOROT_UNIFORM),
```

```
            tf.keras.layers.Activation(GELU),
            tf.keras.layers.Dense(self.units, name=f'{self.name}_dense_2',␣
 ↪use_bias=False, kernel_initializer=INIT_HE_UNIFORM),
        ], name=f'{self.name}_dense')

    def call(self, x):
        return tf.where(
                # Checks whether landmark is missing in frame
                tf.reduce_sum(x, axis=2, keepdims=True) == 0,
                # If so, the empty embedding is used
                self.empty_embedding,
                # Otherwise the landmark data is embedded
                self.dense(x),
            )
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
class Embedding(tf.keras.Model):
    def __init__(self):
        super(Embedding, self).__init__()

    def get_diffs(self, l):
        S = l.shape[2]
        other = tf.expand_dims(l, 3)
        other = tf.repeat(other, S, axis=3)
        other = tf.transpose(other, [0,1,3,2])
        diffs = tf.expand_dims(l, 3) - other
        diffs = tf.reshape(diffs, [-1, INPUT_SIZE, S*S])
        return diffs

    def build(self, input_shape):
        # Positional Embedding, initialized with zeros
        self.positional_embedding = tf.keras.layers.Embedding(INPUT_SIZE+1,␣
 ↪UNITS, embeddings_initializer=INIT_ZEROS)
        # Embedding layer for Landmarks
        self.lips_embedding = LandmarkEmbedding(LIPS_UNITS, 'lips')
        self.left_hand_embedding = LandmarkEmbedding(HANDS_UNITS, 'left_hand')
        self.pose_embedding = LandmarkEmbedding(POSE_UNITS, 'pose')
        # Landmark Weights
        self.landmark_weights = tf.Variable(tf.zeros([3], dtype=tf.float32),␣
 ↪name='landmark_weights')
        # Fully Connected Layers for combined landmarks
        self.fc = tf.keras.Sequential([
            tf.keras.layers.Dense(UNITS, name='fully_connected_1',␣
 ↪use_bias=False, kernel_initializer=INIT_GLOROT_UNIFORM),
            tf.keras.layers.Activation(GELU),
```

```
            tf.keras.layers.Dense(UNITS, name='fully_connected_2',␣
↪use_bias=False, kernel_initializer=INIT_HE_UNIFORM),
        ], name='fc')


    def call(self, lips0, left_hand0, pose0, non_empty_frame_idxs,␣
↪training=False):
        # Lips
        lips_embedding = self.lips_embedding(lips0)
        # Left Hand
        left_hand_embedding = self.left_hand_embedding(left_hand0)
        # Pose
        pose_embedding = self.pose_embedding(pose0)
        # Merge Embeddings of all landmarks with mean pooling
        x = tf.stack((
            lips_embedding, left_hand_embedding, pose_embedding,
        ), axis=3)
        x = x * tf.nn.softmax(self.landmark_weights)
        x = tf.reduce_sum(x, axis=3)
        # Fully Connected Layers
        x = self.fc(x)
        # Add Positional Embedding
        max_frame_idxs = tf.clip_by_value(
                tf.reduce_max(non_empty_frame_idxs, axis=1, keepdims=True),
                1,
                np.PINF,
            )
        normalised_non_empty_frame_idxs = tf.where(
            tf.math.equal(non_empty_frame_idxs, -1.0),
            INPUT_SIZE,
            tf.cast(
                non_empty_frame_idxs / max_frame_idxs * INPUT_SIZE,
                tf.int32,
            ),
        )
        x = x + self.positional_embedding(normalised_non_empty_frame_idxs)

        return x
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
↪gislr-tf-data-processing-transformer-training
# source:: https://stackoverflow.com/questions/60689185/
↪label-smoothing-for-sparse-categorical-crossentropy
def scce_with_ls(y_true, y_pred):
    # One Hot Encode Sparsely Encoded Target Sign
    y_true = tf.cast(y_true, tf.int32)
    y_true = tf.one_hot(y_true, NUM_CLASSES, axis=1)
```

```
    y_true = tf.squeeze(y_true, axis=2)
    # Categorical Crossentropy with native label smoothing support
    return tf.keras.losses.categorical_crossentropy(y_true, y_pred,␣
 ↪label_smoothing=0.25)
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
def get_model():
    # Inputs
    frames = tf.keras.layers.Input([INPUT_SIZE, N_COLS, N_DIMS], dtype=tf.
 ↪float32, name='frames')
    non_empty_frame_idxs = tf.keras.layers.Input([INPUT_SIZE], dtype=tf.
 ↪float32, name='non_empty_frame_idxs')
    # Padding Mask
    mask0 = tf.cast(tf.math.not_equal(non_empty_frame_idxs, -1), tf.float32)
    mask0 = tf.expand_dims(mask0, axis=2)
    # Random Frame Masking
    mask = tf.where(
        (tf.random.uniform(tf.shape(mask0)) > 0.25) & tf.math.not_equal(mask0,␣
 ↪0.0),
        1.0,
        0.0,
    )
    # Correct Samples Which are all masked now...
    mask = tf.where(
        tf.math.equal(tf.reduce_sum(mask, axis=[1,2], keepdims=True), 0.0),
        mask0,
        mask,
    )


    """
        left_hand: 468:489
        pose: 489:522
        right_hand: 522:543
    """
    x = frames
    x = tf.slice(x, [0,0,0,0], [-1,INPUT_SIZE, N_COLS, 2])
    # LIPS
    lips = tf.slice(x, [0,0,LIPS_START,0], [-1,INPUT_SIZE, 40, 2])
    lips = tf.where(
            tf.math.equal(lips, 0.0),
            0.0,
            (lips - LIPS_MEAN) / LIPS_STD,
        )
    # LEFT HAND
    left_hand = tf.slice(x, [0,0,40,0], [-1,INPUT_SIZE, 21, 2])
```

```
    left_hand = tf.where(
            tf.math.equal(left_hand, 0.0),
            0.0,
            (left_hand - LEFT_HANDS_MEAN) / LEFT_HANDS_STD,
        )
    # POSE
    pose = tf.slice(x, [0,0,61,0], [-1,INPUT_SIZE, 5, 2])
    pose = tf.where(
            tf.math.equal(pose, 0.0),
            0.0,
            (pose - POSE_MEAN) / POSE_STD,
        )

    # Flatten
    lips = tf.reshape(lips, [-1, INPUT_SIZE, 40*2])
    left_hand = tf.reshape(left_hand, [-1, INPUT_SIZE, 21*2])
    pose = tf.reshape(pose, [-1, INPUT_SIZE, 5*2])

    # Embedding
    x = Embedding()(lips, left_hand, pose, non_empty_frame_idxs)

    # Encoder Transformer Blocks
    x = Transformer(NUM_BLOCKS)(x, mask)

    # Pooling
    x = tf.reduce_sum(x * mask, axis=1) / tf.reduce_sum(mask, axis=1)
    # Classifier Dropout
    x = tf.keras.layers.Dropout(CLASSIFIER_DROPOUT_RATIO)(x)
    # Classification Layer
    x = tf.keras.layers.Dense(NUM_CLASSES, activation=tf.keras.activations.
↪softmax, kernel_initializer=INIT_GLOROT_UNIFORM)(x)

    outputs = x

    # Create Tensorflow Model
    model = tf.keras.models.Model(inputs=[frames, non_empty_frame_idxs],␣
↪outputs=outputs)

    # Sparse Categorical Cross Entropy With Label Smoothing
    loss = scce_with_ls

    # Adam Optimizer with weight decay
    optimizer = tfa.optimizers.AdamW(learning_rate=1e-3, weight_decay=1e-5,␣
↪clipnorm=1.0)

    # TopK Metrics
    metrics = [
```

```
        tf.keras.metrics.SparseCategoricalAccuracy(name='acc'),
        tf.keras.metrics.SparseTopKCategoricalAccuracy(k=5, name='top_5_acc'),
        tf.keras.metrics.SparseTopKCategoricalAccuracy(k=10, name='top_10_acc'),
    ]

    model.compile(loss=loss, optimizer=optimizer, metrics=metrics)

    return model
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
  ↪gislr-tf-data-processing-transformer-training
tf.keras.backend.clear_session()

model = get_model()
```

[ ]:
```
# Plot model summary
model.summary(expand_nested=True)
```

```
Model: "model"
__________________________________________________________________________________
__________________
 Layer (type)                Output Shape                 Param #   Connected to
==================================================================================
==================
 non_empty_frame_idxs (Inpu  [(None, 64)]                 0         []
 tLayer)

 tf.math.not_equal (TFOpLam  (None, 64)                   0
['non_empty_frame_idxs[0][0]']
 bda)

 tf.cast (TFOpLambda)        (None, 64)                   0
['tf.math.not_equal[0][0]']

 tf.expand_dims (TFOpLambda  (None, 64, 1)                0
['tf.cast[0][0]']
 )

 frames (InputLayer)         [(None, 64, 66, 3)]          0         []

 tf.compat.v1.shape (TFOpLa  (3,)                         0
['tf.expand_dims[0][0]']
 mbda)

 tf.slice (TFOpLambda)       (None, 64, 66, 2)            0
['frames[0][0]']

 tf.random.uniform (TFOpLam  (None, 64, 1)                0
```

```
['tf.compat.v1.shape[0][0]']
 bda)

 tf.slice_1 (TFOpLambda)     (None, 64, 40, 2)           0
['tf.slice[0][0]']

 tf.slice_2 (TFOpLambda)     (None, 64, 21, 2)           0
['tf.slice[0][0]']

 tf.slice_3 (TFOpLambda)     (None, 64, 5, 2)            0
['tf.slice[0][0]']

 tf.math.greater (TFOpLambd  (None, 64, 1)               0
['tf.random.uniform[0][0]']
 a)

 tf.math.not_equal_1 (TFOpL  (None, 64, 1)               0
['tf.expand_dims[0][0]']
 ambda)

 tf.math.subtract (TFOpLamb  (None, 64, 40, 2)           0
['tf.slice_1[0][0]']
 da)

 tf.math.subtract_1 (TFOpLa  (None, 64, 21, 2)           0
['tf.slice_2[0][0]']
 mbda)

 tf.math.subtract_2 (TFOpLa  (None, 64, 5, 2)            0
['tf.slice_3[0][0]']
 mbda)

 tf.math.logical_and (TFOpL  (None, 64, 1)               0
['tf.math.greater[0][0]',
 ambda)
'tf.math.not_equal_1[0][0]']

 tf.math.equal_1 (TFOpLambd  (None, 64, 40, 2)           0
['tf.slice_1[0][0]']
 a)

 tf.math.truediv (TFOpLambd  (None, 64, 40, 2)           0
['tf.math.subtract[0][0]']
 a)

 tf.math.equal_2 (TFOpLambd  (None, 64, 21, 2)           0
['tf.slice_2[0][0]']
 a)
```

```
 tf.math.truediv_1 (TFOpLam  (None, 64, 21, 2)           0
['tf.math.subtract_1[0][0]']
 bda)

 tf.math.equal_3 (TFOpLambd  (None, 64, 5, 2)            0
['tf.slice_3[0][0]']
 a)

 tf.math.truediv_2 (TFOpLam  (None, 64, 5, 2)            0
['tf.math.subtract_2[0][0]']
 bda)

 tf.where (TFOpLambda)       (None, 64, 1)               0
['tf.math.logical_and[0][0]']

 tf.where_2 (TFOpLambda)     (None, 64, 40, 2)           0
['tf.math.equal_1[0][0]',
'tf.math.truediv[0][0]']

 tf.where_3 (TFOpLambda)     (None, 64, 21, 2)           0
['tf.math.equal_2[0][0]',
'tf.math.truediv_1[0][0]']

 tf.where_4 (TFOpLambda)     (None, 64, 5, 2)            0
['tf.math.equal_3[0][0]',
'tf.math.truediv_2[0][0]']

 tf.math.reduce_sum (TFOpLa  (None, 1, 1)                0
['tf.where[0][0]']
 mbda)

 tf.reshape (TFOpLambda)     (None, 64, 80)              0
['tf.where_2[0][0]']

 tf.reshape_1 (TFOpLambda)   (None, 64, 42)              0
['tf.where_3[0][0]']

 tf.reshape_2 (TFOpLambda)   (None, 64, 10)              0
['tf.where_4[0][0]']

 tf.math.equal (TFOpLambda)  (None, 1, 1)                0
['tf.math.reduce_sum[0][0]']

 embedding (Embedding)       (None, 64, 512)             986243
['tf.reshape[0][0]',
'tf.reshape_1[0][0]',
'tf.reshape_2[0][0]',
```

```
'non_empty_frame_idxs[0][0]']
|-------------------------------------------------------------------------------
-----------------|
| embedding (Embedding)      multiple                  33280     []
|
|
|
| lips_embedding (LandmarkE  multiple                  178560    []
|
| mbedding)
|
||-----------------------------------------------------------------------------
----------------||
|| lips_embedding_dense (Se  (None, 64, 384)           178176    []
||
|| quential)
||
|||----------------------------------------------------------------------------
---------------|||
||| lips_embedding_dense_1   (None, 64, 384)           30720     []
|||
||| (Dense)
|||
|||
|||
||| activation_1 (Activatio  (None, 64, 384)           0         []
|||
||| n)
|||
|||
|||
||| lips_embedding_dense_2   (None, 64, 384)           147456    []
|||
||| (Dense)
|||
||-----------------------------------------------------------------------------
----------------||
|-------------------------------------------------------------------------------
-----------------|
| left_hand_embedding (Land  multiple                  163968    []
|
| markEmbedding)
|
||-----------------------------------------------------------------------------
----------------||
|| left_hand_embedding_dens  (None, 64, 384)           163584    []
||
|| e (Sequential)
```

```
||
|||--------------------------------------------------------------------------
---------------|||
||| left_hand_embedding_den  (None, 64, 384)             16128     []
|||
||| se_1 (Dense)
|||
|||
|||
||| activation_2 (Activatio  (None, 64, 384)             0         []
|||
||| n)
|||
|||
|||
||| left_hand_embedding_den  (None, 64, 384)             147456    []
|||
||| se_2 (Dense)
|||
||--------------------------------------------------------------------------
----------------||
|--------------------------------------------------------------------------
-----------------|
| pose_embedding (LandmarkE  multiple                  151680    []
|
| mbedding)
|
||--------------------------------------------------------------------------
----------------||
|| pose_embedding_dense (Se  (None, 64, 384)             151296    []
||
|| quential)
||
|||--------------------------------------------------------------------------
---------------|||
||| pose_embedding_dense_1   (None, 64, 384)             3840      []
|||
||| (Dense)
|||
|||
|||
||| activation_3 (Activatio  (None, 64, 384)             0         []
|||
||| n)
|||
|||
|||
||| pose_embedding_dense_2   (None, 64, 384)             147456    []
```

```
|||
||| (Dense)
|||
||-------------------------------------------------------------------------------
---------------||
|-------------------------------------------------------------------------------
----------------|
| fc (Sequential)            (None, 64, 512)             458752    []
|
||-------------------------------------------------------------------------------
---------------||
|| fully_connected_1 (Dense  (None, 64, 512)             196608    []
||
|| )
||
||
||
|| activation (Activation)   (None, 64, 512)             0         []
||
||
||
|| fully_connected_2 (Dense  (None, 64, 512)             262144    []
||
|| )
||
|-------------------------------------------------------------------------------
----------------|
-------------------------------------------------------------------------------
-----------------
 tf.where_1 (TFOpLambda)     (None, 64, 1)               0
['tf.math.equal[0][0]',
'tf.expand_dims[0][0]',
'tf.where[0][0]']

 transformer (Transformer)   (None, 64, 512)             4201472
['embedding[0][0]',
'tf.where_1[0][0]']
|-------------------------------------------------------------------------------
----------------|
| multi_head_attention (Mul  multiple                    1050624   []
|
| tiHeadAttention)
|
|
|
| multi_head_attention_1 (M  multiple                    1050624   []
|
| ultiHeadAttention)
```

```
|
|
|
| sequential (Sequential)    (None, 64, 512)             1050112   []
|
||--------------------------------------------------------------------------
----------------||
|| dense_25 (Dense)          (None, 64, 1024)            525312    []
||
||
||
|| dropout (Dropout)         (None, 64, 1024)            0         []
||
||
||
|| dense_26 (Dense)          (None, 64, 512)             524800    []
||
|--------------------------------------------------------------------------
-----------------|
| sequential_1 (Sequential)  (None, 64, 512)             1050112   []
|
||--------------------------------------------------------------------------
----------------||
|| dense_52 (Dense)          (None, 64, 1024)            525312    []
||
||
||
|| dropout_1 (Dropout)       (None, 64, 1024)            0         []
||
||
||
|| dense_53 (Dense)          (None, 64, 512)             524800    []
||
|--------------------------------------------------------------------------
-----------------|
--------------------------------------------------------------------------
------------------
 tf.math.multiply (TFOpLamb  (None, 64, 512)             0
['transformer[0][0]',
 da)
'tf.where_1[0][0]']

 tf.math.reduce_sum_1 (TFOp  (None, 512)                 0
['tf.math.multiply[0][0]']
 Lambda)

 tf.math.reduce_sum_2 (TFOp  (None, 1)                   0
['tf.where_1[0][0]']
```

```
 Lambda)

 tf.math.truediv_3 (TFOpLam  (None, 512)                  0
['tf.math.reduce_sum_1[0][0]',
 bda)
'tf.math.reduce_sum_2[0][0]']

 dropout (Dropout)           (None, 512)                  0
['tf.math.truediv_3[0][0]']

 dense (Dense)               (None, 250)                  128250
['dropout[0][0]']

==================================================================================
==================
Total params: 5315965 (20.28 MB)
Trainable params: 5315965 (20.28 MB)
Non-trainable params: 0 (0.00 Byte)
----------------------------------------------------------------------------------
------------------
```

[ ]:
```python
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
def get_train_batch_all_signs(X, y, NON_EMPTY_FRAME_IDXS, n=BATCH_ALL_SIGNS_N):
    # Arrays to store batch in
    X_batch = np.zeros([NUM_CLASSES*n, INPUT_SIZE, N_COLS, N_DIMS], dtype=np.
 ↪float32)
    y_batch = np.arange(0, NUM_CLASSES, step=1/n, dtype=np.float32).astype(np.
 ↪int64)
    non_empty_frame_idxs_batch = np.zeros([NUM_CLASSES*n, INPUT_SIZE], dtype=np.
 ↪float32)

    # Dictionary mapping ordinally encoded sign to corresponding sample indices
    CLASS2IDXS = {}
    for i in range(NUM_CLASSES):
        CLASS2IDXS[i] = np.argwhere(y == i).squeeze().astype(np.int32)

    while True:
        # Fill batch arrays
        for i in range(NUM_CLASSES):
            idxs = np.random.choice(CLASS2IDXS[i], n)
            X_batch[i*n:(i+1)*n] = X[idxs]
            non_empty_frame_idxs_batch[i*n:(i+1)*n] = NON_EMPTY_FRAME_IDXS[idxs]

        yield { 'frames': X_batch, 'non_empty_frame_idxs':␣
 ↪non_empty_frame_idxs_batch }, y_batch
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
 # Actual Training
history = model.fit(
            x=get_train_batch_all_signs(X_train, y_train,␣
 ↪NON_EMPTY_FRAME_IDXS_TRAIN),
            steps_per_epoch=len(X_train) // (NUM_CLASSES * BATCH_ALL_SIGNS_N),
            epochs=N_EPOCHS,
            batch_size=BATCH_SIZE,
        )
```

```
Epoch 1/100
94/94 [==============================] - 42s 288ms/step - loss: 4.2173 - acc:
0.3037 - top_5_acc: 0.5661 - top_10_acc: 0.6701
Epoch 2/100
94/94 [==============================] - 27s 289ms/step - loss: 3.2221 - acc:
0.6053 - top_5_acc: 0.8466 - top_10_acc: 0.8972
Epoch 3/100
94/94 [==============================] - 27s 289ms/step - loss: 2.9747 - acc:
0.6914 - top_5_acc: 0.8920 - top_10_acc: 0.9267
Epoch 4/100
94/94 [==============================] - 27s 289ms/step - loss: 2.8269 - acc:
0.7456 - top_5_acc: 0.9165 - top_10_acc: 0.9434
Epoch 5/100
94/94 [==============================] - 27s 290ms/step - loss: 2.7447 - acc:
0.7771 - top_5_acc: 0.9294 - top_10_acc: 0.9516
Epoch 6/100
94/94 [==============================] - 27s 289ms/step - loss: 2.6789 - acc:
0.8014 - top_5_acc: 0.9391 - top_10_acc: 0.9584
Epoch 7/100
94/94 [==============================] - 27s 289ms/step - loss: 2.6201 - acc:
0.8235 - top_5_acc: 0.9478 - top_10_acc: 0.9649
Epoch 8/100
94/94 [==============================] - 27s 289ms/step - loss: 2.5751 - acc:
0.8415 - top_5_acc: 0.9536 - top_10_acc: 0.9686
Epoch 9/100
94/94 [==============================] - 27s 290ms/step - loss: 2.5478 - acc:
0.8520 - top_5_acc: 0.9576 - top_10_acc: 0.9714
Epoch 10/100
94/94 [==============================] - 27s 290ms/step - loss: 2.5127 - acc:
0.8654 - top_5_acc: 0.9631 - top_10_acc: 0.9758
Epoch 11/100
94/94 [==============================] - 27s 290ms/step - loss: 2.4809 - acc:
0.8769 - top_5_acc: 0.9666 - top_10_acc: 0.9783
Epoch 12/100
94/94 [==============================] - 27s 290ms/step - loss: 2.4417 - acc:
0.8904 - top_5_acc: 0.9726 - top_10_acc: 0.9819
Epoch 13/100
```

```
94/94 [==============================] - 27s 289ms/step - loss: 2.4155 - acc:
0.9008 - top_5_acc: 0.9757 - top_10_acc: 0.9844
Epoch 14/100
94/94 [==============================] - 27s 289ms/step - loss: 2.3976 - acc:
0.9080 - top_5_acc: 0.9781 - top_10_acc: 0.9854
Epoch 15/100
94/94 [==============================] - 27s 289ms/step - loss: 2.3756 - acc:
0.9167 - top_5_acc: 0.9802 - top_10_acc: 0.9877
Epoch 16/100
94/94 [==============================] - 27s 289ms/step - loss: 2.3633 - acc:
0.9186 - top_5_acc: 0.9829 - top_10_acc: 0.9890
Epoch 17/100
94/94 [==============================] - 27s 289ms/step - loss: 2.3410 - acc:
0.9281 - top_5_acc: 0.9855 - top_10_acc: 0.9910
Epoch 18/100
94/94 [==============================] - 27s 289ms/step - loss: 2.3249 - acc:
0.9336 - top_5_acc: 0.9872 - top_10_acc: 0.9918
Epoch 19/100
94/94 [==============================] - 27s 290ms/step - loss: 2.3132 - acc:
0.9374 - top_5_acc: 0.9881 - top_10_acc: 0.9925
Epoch 20/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2979 - acc:
0.9426 - top_5_acc: 0.9896 - top_10_acc: 0.9935
Epoch 21/100
94/94 [==============================] - 27s 290ms/step - loss: 2.3075 - acc:
0.9397 - top_5_acc: 0.9897 - top_10_acc: 0.9936
Epoch 22/100
94/94 [==============================] - 27s 290ms/step - loss: 2.3025 - acc:
0.9417 - top_5_acc: 0.9903 - top_10_acc: 0.9942
Epoch 23/100
94/94 [==============================] - 27s 290ms/step - loss: 2.3011 - acc:
0.9415 - top_5_acc: 0.9900 - top_10_acc: 0.9943
Epoch 24/100
94/94 [==============================] - 27s 290ms/step - loss: 2.2876 - acc:
0.9467 - top_5_acc: 0.9918 - top_10_acc: 0.9953
Epoch 25/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2829 - acc:
0.9479 - top_5_acc: 0.9916 - top_10_acc: 0.9953
Epoch 26/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2687 - acc:
0.9527 - top_5_acc: 0.9929 - top_10_acc: 0.9959
Epoch 27/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2690 - acc:
0.9524 - top_5_acc: 0.9933 - top_10_acc: 0.9964
Epoch 28/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2601 - acc:
0.9558 - top_5_acc: 0.9935 - top_10_acc: 0.9964
Epoch 29/100
```

```
94/94 [==============================] - 27s 289ms/step - loss: 2.2520 - acc:
0.9573 - top_5_acc: 0.9946 - top_10_acc: 0.9972
Epoch 30/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2379 - acc:
0.9621 - top_5_acc: 0.9955 - top_10_acc: 0.9977
Epoch 31/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2370 - acc:
0.9622 - top_5_acc: 0.9955 - top_10_acc: 0.9979
Epoch 32/100
94/94 [==============================] - 27s 290ms/step - loss: 2.2318 - acc:
0.9652 - top_5_acc: 0.9961 - top_10_acc: 0.9980
Epoch 33/100
94/94 [==============================] - 27s 290ms/step - loss: 2.2305 - acc:
0.9648 - top_5_acc: 0.9962 - top_10_acc: 0.9982
Epoch 34/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2247 - acc:
0.9660 - top_5_acc: 0.9964 - top_10_acc: 0.9982
Epoch 35/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2205 - acc:
0.9678 - top_5_acc: 0.9966 - top_10_acc: 0.9984
Epoch 36/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2179 - acc:
0.9688 - top_5_acc: 0.9971 - top_10_acc: 0.9987
Epoch 37/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2055 - acc:
0.9722 - top_5_acc: 0.9974 - top_10_acc: 0.9987
Epoch 38/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2027 - acc:
0.9727 - top_5_acc: 0.9977 - top_10_acc: 0.9989
Epoch 39/100
94/94 [==============================] - 27s 289ms/step - loss: 2.2105 - acc:
0.9707 - top_5_acc: 0.9973 - top_10_acc: 0.9988
Epoch 40/100
94/94 [==============================] - 27s 290ms/step - loss: 2.2054 - acc:
0.9711 - top_5_acc: 0.9976 - top_10_acc: 0.9989
Epoch 41/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1922 - acc:
0.9750 - top_5_acc: 0.9982 - top_10_acc: 0.9993
Epoch 42/100
94/94 [==============================] - 27s 290ms/step - loss: 2.1982 - acc:
0.9738 - top_5_acc: 0.9981 - top_10_acc: 0.9992
Epoch 43/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1949 - acc:
0.9749 - top_5_acc: 0.9982 - top_10_acc: 0.9992
Epoch 44/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1857 - acc:
0.9764 - top_5_acc: 0.9984 - top_10_acc: 0.9994
Epoch 45/100
```

```
94/94 [==============================] - 27s 289ms/step - loss: 2.1912 - acc:
0.9758 - top_5_acc: 0.9983 - top_10_acc: 0.9993
Epoch 46/100
94/94 [==============================] - 27s 290ms/step - loss: 2.1903 - acc:
0.9758 - top_5_acc: 0.9984 - top_10_acc: 0.9993
Epoch 47/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1784 - acc:
0.9786 - top_5_acc: 0.9987 - top_10_acc: 0.9996
Epoch 48/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1704 - acc:
0.9811 - top_5_acc: 0.9989 - top_10_acc: 0.9996
Epoch 49/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1703 - acc:
0.9803 - top_5_acc: 0.9989 - top_10_acc: 0.9996
Epoch 50/100
94/94 [==============================] - 27s 290ms/step - loss: 2.1741 - acc:
0.9802 - top_5_acc: 0.9988 - top_10_acc: 0.9996
Epoch 51/100
94/94 [==============================] - 27s 290ms/step - loss: 2.1773 - acc:
0.9787 - top_5_acc: 0.9989 - top_10_acc: 0.9996
Epoch 52/100
94/94 [==============================] - 27s 290ms/step - loss: 2.1895 - acc:
0.9758 - top_5_acc: 0.9983 - top_10_acc: 0.9994
Epoch 53/100
94/94 [==============================] - 27s 290ms/step - loss: 2.1776 - acc:
0.9786 - top_5_acc: 0.9989 - top_10_acc: 0.9995
Epoch 54/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1705 - acc:
0.9809 - top_5_acc: 0.9989 - top_10_acc: 0.9996
Epoch 55/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1683 - acc:
0.9813 - top_5_acc: 0.9990 - top_10_acc: 0.9997
Epoch 56/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1692 - acc:
0.9815 - top_5_acc: 0.9992 - top_10_acc: 0.9997
Epoch 57/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1559 - acc:
0.9844 - top_5_acc: 0.9994 - top_10_acc: 0.9997
Epoch 58/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1526 - acc:
0.9845 - top_5_acc: 0.9994 - top_10_acc: 0.9997
Epoch 59/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1511 - acc:
0.9845 - top_5_acc: 0.9993 - top_10_acc: 0.9997
Epoch 60/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1535 - acc:
0.9843 - top_5_acc: 0.9993 - top_10_acc: 0.9997
Epoch 61/100
```

```
94/94 [==============================] - 27s 289ms/step - loss: 2.1590 - acc:
0.9825 - top_5_acc: 0.9992 - top_10_acc: 0.9997
Epoch 62/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1572 - acc:
0.9833 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 63/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1666 - acc:
0.9821 - top_5_acc: 0.9992 - top_10_acc: 0.9997
Epoch 64/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1678 - acc:
0.9811 - top_5_acc: 0.9991 - top_10_acc: 0.9997
Epoch 65/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1628 - acc:
0.9815 - top_5_acc: 0.9993 - top_10_acc: 0.9997
Epoch 66/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1541 - acc:
0.9847 - top_5_acc: 0.9993 - top_10_acc: 0.9998
Epoch 67/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1525 - acc:
0.9843 - top_5_acc: 0.9994 - top_10_acc: 0.9998
Epoch 68/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1575 - acc:
0.9831 - top_5_acc: 0.9992 - top_10_acc: 0.9997
Epoch 69/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1523 - acc:
0.9844 - top_5_acc: 0.9994 - top_10_acc: 0.9998
Epoch 70/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1410 - acc:
0.9874 - top_5_acc: 0.9996 - top_10_acc: 0.9998
Epoch 71/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1442 - acc:
0.9857 - top_5_acc: 0.9994 - top_10_acc: 0.9998
Epoch 72/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1475 - acc:
0.9847 - top_5_acc: 0.9993 - top_10_acc: 0.9998
Epoch 73/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1403 - acc:
0.9864 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 74/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1412 - acc:
0.9866 - top_5_acc: 0.9994 - top_10_acc: 0.9998
Epoch 75/100
94/94 [==============================] - 27s 288ms/step - loss: 2.1335 - acc:
0.9878 - top_5_acc: 0.9997 - top_10_acc: 0.9999
Epoch 76/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1281 - acc:
0.9895 - top_5_acc: 0.9997 - top_10_acc: 0.9999
Epoch 77/100
```

```
94/94 [==============================] - 27s 289ms/step - loss: 2.1360 - acc:
0.9873 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 78/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1532 - acc:
0.9840 - top_5_acc: 0.9995 - top_10_acc: 0.9999
Epoch 79/100
94/94 [==============================] - 27s 290ms/step - loss: 2.1564 - acc:
0.9834 - top_5_acc: 0.9993 - top_10_acc: 0.9998
Epoch 80/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1567 - acc:
0.9831 - top_5_acc: 0.9992 - top_10_acc: 0.9997
Epoch 81/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1417 - acc:
0.9863 - top_5_acc: 0.9994 - top_10_acc: 0.9998
Epoch 82/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1382 - acc:
0.9867 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 83/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1365 - acc:
0.9868 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 84/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1304 - acc:
0.9885 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 85/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1263 - acc:
0.9893 - top_5_acc: 0.9996 - top_10_acc: 0.9998
Epoch 86/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1250 - acc:
0.9895 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 87/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1359 - acc:
0.9866 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 88/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1266 - acc:
0.9887 - top_5_acc: 0.9997 - top_10_acc: 0.9999
Epoch 89/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1296 - acc:
0.9888 - top_5_acc: 0.9996 - top_10_acc: 0.9998
Epoch 90/100
94/94 [==============================] - 27s 290ms/step - loss: 2.1210 - acc:
0.9897 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 91/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1182 - acc:
0.9900 - top_5_acc: 0.9998 - top_10_acc: 0.9999
Epoch 92/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1162 - acc:
0.9908 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 93/100
```

```
94/94 [==============================] - 27s 289ms/step - loss: 2.1208 - acc:
0.9899 - top_5_acc: 0.9997 - top_10_acc: 0.9999
Epoch 94/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1252 - acc:
0.9887 - top_5_acc: 0.9996 - top_10_acc: 0.9998
Epoch 95/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1257 - acc:
0.9892 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 96/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1282 - acc:
0.9881 - top_5_acc: 0.9994 - top_10_acc: 0.9997
Epoch 97/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1302 - acc:
0.9875 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 98/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1324 - acc:
0.9881 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 99/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1339 - acc:
0.9868 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 100/100
94/94 [==============================] - 27s 289ms/step - loss: 2.1351 - acc:
0.9865 - top_5_acc: 0.9996 - top_10_acc: 0.9999
```

[ ]:
```
model.save_weights('/content/drive/MyDrive/Colab Notebooks/Data/asl-signs/
↪transformerModel')
```

Reference:

Wijkhuizen, M. (2023, April 04). GISLR TF Data Processing & Transformer Training. Kaggle. https://www.kaggle.com/code/markwijkhuizen/gislr-tf-data-processing-transformer-training

Modeling

December 11, 2023

During our study of the data and research on the possible model solutions, there is one transformer model approach caught our eye. This transformer model approach was designed by Wijkhuizen, M., in the Kaggle competition (2023). Our project team decided to follow Wijkhuizen, M.'s approach to create a transformer model as one of the models to test for this project. Our goal with this approach is to get a better understanding of the transformer model since Wijkhuizen, M.'s approach is to build a transformer model from scratch and not fine-turn a base model.

[ ]:
```
!pip install tensorflow-addons
```

```
Collecting tensorflow-addons
  Downloading tensorflow_addons-0.23.0-cp310-cp310-
manylinux_2_17_x86_64.manylinux2014_x86_64.whl (611 kB)
                           611.8/611.8
kB 10.8 MB/s eta 0:00:00
Requirement already satisfied: packaging in
/usr/local/lib/python3.10/dist-packages (from tensorflow-addons) (23.2)
Collecting typeguard<3.0.0,>=2.7 (from tensorflow-addons)
  Downloading typeguard-2.13.3-py3-none-any.whl (17 kB)
Installing collected packages: typeguard, tensorflow-addons
Successfully installed tensorflow-addons-0.23.0 typeguard-2.13.3
```

[ ]:
```
import numpy as np
import pandas as pd
import tensorflow as tf
import tensorflow_addons as tfa
import matplotlib.pyplot as plt
import matplotlib as mpl
import seaborn as sn

from tqdm.notebook import tqdm
from sklearn.model_selection import train_test_split, GroupShuffleSplit

import glob
import sys
import os
import math
import gc
import sys
```

```
import sklearn
import scipy
```

```
/usr/local/lib/python3.10/dist-
packages/tensorflow_addons/utils/tfa_eol_msg.py:23: UserWarning:

TensorFlow Addons (TFA) has ended development and introduction of new features.
TFA has entered a minimal maintenance and release mode until a planned end of
life in May 2024.
Please modify downstream libraries to take dependencies from other repositories
in our TensorFlow community (e.g. Keras, Keras-CV, and Keras-NLP).

For more information see: https://github.com/tensorflow/addons/issues/2807

  warnings.warn(
```

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

```
Mounted at /content/drive
```

[ ]:
```
googledrive_dir = '/content/drive/MyDrive/Colab Notebooks/Data/asl-signs/'
```

[ ]:
```
X_train = np.load(f'{googledrive_dir}/X_train.npy')
y_train = np.load(f'{googledrive_dir}/y_train.npy')
NON_EMPTY_FRAME_IDXS_TRAIN = np.load(f'{googledrive_dir}/
 ↪NON_EMPTY_FRAME_IDXS_TRAIN.npy')
X_val = np.load(f'{googledrive_dir}/X_val.npy')
y_val = np.load(f'{googledrive_dir}/y_val.npy')
NON_EMPTY_FRAME_IDXS_VAL = np.load(f'{googledrive_dir}/NON_EMPTY_FRAME_IDXS_VAL.
 ↪npy')
```

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

[ ]:
```
(80229, 64, 66, 3)
```

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

[ ]:
```
(80229,)
```

[ ]:
```
X_train.dtype
```

[ ]:
```
dtype('float32')
```

[ ]:
```
y_train.dtype
```

[ ]:
```
dtype('int32')
```

[ ]:
```
NON_EMPTY_FRAME_IDXS_TRAIN.shape
```

[ ]: (80229, 64)

[ ]:
```
display(pd.Series(y_train).value_counts().to_frame('Class Count').
 ↪iloc[[0,1,2,3,4, -5,-4,-3,-2,-1]])
```

	Class Count
135	358
136	352
60	351
194	351
67	348
170	277
249	267
56	266
21	263
231	255

[ ]:
```
y_train
```

[ ]: array([25, 232, 48, …, 86, 188, 105], dtype=int32)

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# Epsilon value for layer normalisation
LAYER_NORM_EPS = 1e-6

# Dense layer units for landmarks
LIPS_UNITS = 384
HANDS_UNITS = 384
POSE_UNITS = 384
# final embedding and transformer embedding size
UNITS = 512

# Transformer
NUM_BLOCKS = 2
MLP_RATIO = 2

# Dropout
EMBEDDING_DROPOUT = 0.00
MLP_DROPOUT_RATIO = 0.30
CLASSIFIER_DROPOUT_RATIO = 0.10

# Initiailizers
INIT_HE_UNIFORM = tf.keras.initializers.he_uniform
INIT_GLOROT_UNIFORM = tf.keras.initializers.glorot_uniform
INIT_ZEROS = tf.keras.initializers.constant(0.0)
# Activations
GELU = tf.keras.activations.gelu
```

```
print(f'UNITS: {UNITS}')
```

```
UNITS: 512
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# If True, processing data from scratch
# If False, loads preprocessed data
PREPROCESS_DATA = False
TRAIN_MODEL = True
# True: use 10% of participants as validation set
# False: use all data for training -> gives better LB result
USE_VAL = False

N_ROWS = 543
N_DIMS = 3
DIM_NAMES = ['x', 'y', 'z']
SEED = 42
NUM_CLASSES = 250
IS_INTERACTIVE = True
VERBOSE = 1 if IS_INTERACTIVE else 2

INPUT_SIZE = 64

BATCH_ALL_SIGNS_N = 4
BATCH_SIZE = 256
N_EPOCHS = 100
LR_MAX = 1e-3
N_WARMUP_EPOCHS = 0
WD_RATIO = 0.05
MASK_VAL = 4237
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
USE_TYPES = ['left_hand', 'pose', 'right_hand']
START_IDX = 468
LIPS_IDXS0 = np.array([
        61, 185, 40, 39, 37, 0, 267, 269, 270, 409,
        291, 146, 91, 181, 84, 17, 314, 405, 321, 375,
        78, 191, 80, 81, 82, 13, 312, 311, 310, 415,
        95, 88, 178, 87, 14, 317, 402, 318, 324, 308,
    ])
# Landmark indices in original data
LEFT_HAND_IDXS0 = np.arange(468,489)
RIGHT_HAND_IDXS0 = np.arange(522,543)
LEFT_POSE_IDXS0 = np.array([502, 504, 506, 508, 510])
```

```
RIGHT_POSE_IDXS0 = np.array([503, 505, 507, 509, 511])
LANDMARK_IDXS_LEFT_DOMINANT0 = np.concatenate((LIPS_IDXS0, LEFT_HAND_IDXS0,␣
 ↪LEFT_POSE_IDXS0))
LANDMARK_IDXS_RIGHT_DOMINANT0 = np.concatenate((LIPS_IDXS0, RIGHT_HAND_IDXS0,␣
 ↪RIGHT_POSE_IDXS0))
HAND_IDXS0 = np.concatenate((LEFT_HAND_IDXS0, RIGHT_HAND_IDXS0), axis=0)
N_COLS = LANDMARK_IDXS_LEFT_DOMINANT0.size
# Landmark indices in processed data
LIPS_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0, LIPS_IDXS0)).
 ↪squeeze()
LEFT_HAND_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0,␣
 ↪LEFT_HAND_IDXS0)).squeeze()
RIGHT_HAND_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0,␣
 ↪RIGHT_HAND_IDXS0)).squeeze()
HAND_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0, HAND_IDXS0)).
 ↪squeeze()
POSE_IDXS = np.argwhere(np.isin(LANDMARK_IDXS_LEFT_DOMINANT0, LEFT_POSE_IDXS0)).
 ↪squeeze()

print(f'# HAND_IDXS: {len(HAND_IDXS)}, N_COLS: {N_COLS}')
```

```
# HAND_IDXS: 21, N_COLS: 66
```

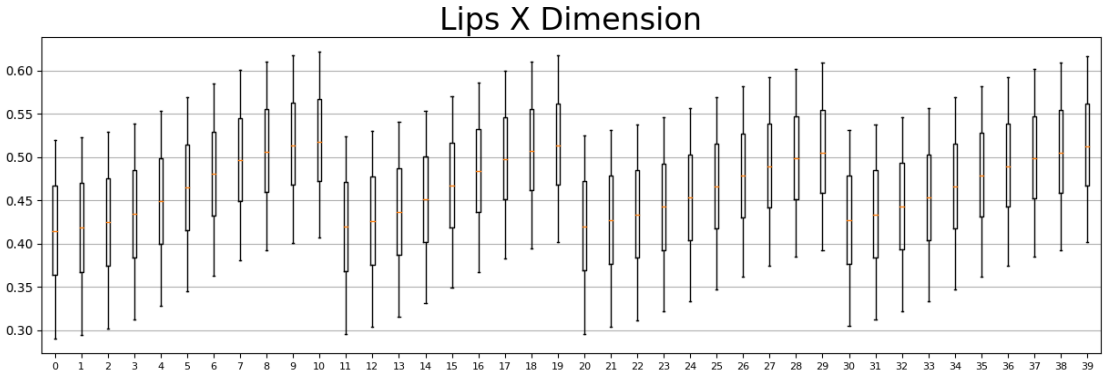
[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
LIPS_START = 0
LEFT_HAND_START = LIPS_IDXS.size
RIGHT_HAND_START = LEFT_HAND_START + LEFT_HAND_IDXS.size
POSE_START = RIGHT_HAND_START + RIGHT_HAND_IDXS.size

print(f'LIPS_START: {LIPS_START}, LEFT_HAND_START: {LEFT_HAND_START},␣
 ↪RIGHT_HAND_START: {RIGHT_HAND_START}, POSE_START: {POSE_START}')
```

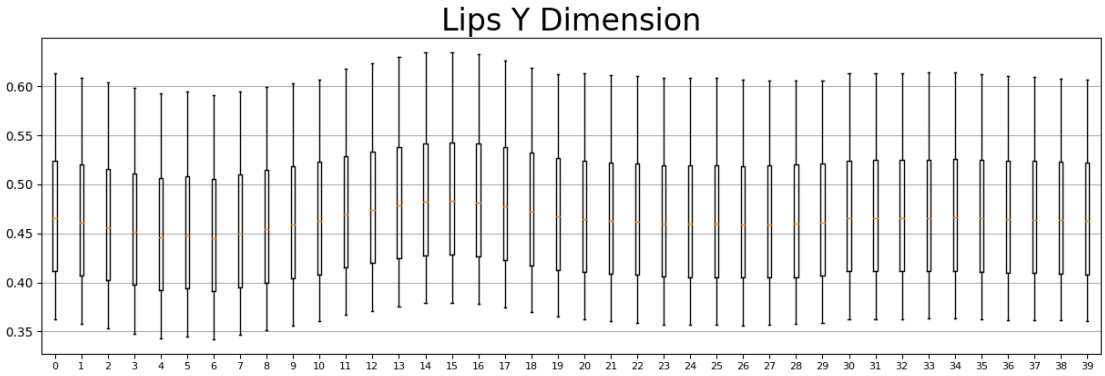
```
LIPS_START: 0, LEFT_HAND_START: 40, RIGHT_HAND_START: 61, POSE_START: 61
```

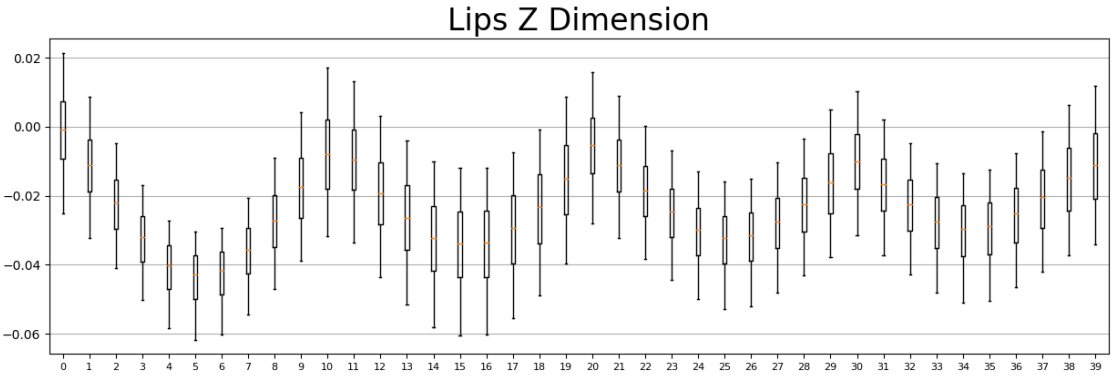
[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
def get_lips_mean_std():
    # LIPS
    LIPS_MEAN_X = np.zeros([LIPS_IDXS.size], dtype=np.float32)
    LIPS_MEAN_Y = np.zeros([LIPS_IDXS.size], dtype=np.float32)
    LIPS_STD_X = np.zeros([LIPS_IDXS.size], dtype=np.float32)
    LIPS_STD_Y = np.zeros([LIPS_IDXS.size], dtype=np.float32)

    fig, axes = plt.subplots(3, 1, figsize=(15, N_DIMS*6))
```

```
    for col, ll in enumerate(tqdm( np.transpose(X_train[:,:,LIPS_IDXS],␣
↪[2,3,0,1]).reshape([LIPS_IDXS.size, N_DIMS, -1]) )):
        for dim, l in enumerate(ll):
            v = l[np.nonzero(l)]
            if dim == 0: # X
                LIPS_MEAN_X[col] = v.mean()
                LIPS_STD_X[col] = v.std()
            if dim == 1: # Y
                LIPS_MEAN_Y[col] = v.mean()
                LIPS_STD_Y[col] = v.std()

            axes[dim].boxplot(v, notch=False, showfliers=False,␣
↪positions=[col], whis=[5,95])

    for ax, dim_name in zip(axes, DIM_NAMES):
        ax.set_title(f'Lips {dim_name.upper()} Dimension', size=24)
        ax.tick_params(axis='x', labelsize=8)
        ax.grid(axis='y')

    plt.subplots_adjust(hspace=0.50)
    plt.show()

    LIPS_MEAN = np.array([LIPS_MEAN_X, LIPS_MEAN_Y]).T
    LIPS_STD = np.array([LIPS_STD_X, LIPS_STD_Y]).T

    return LIPS_MEAN, LIPS_STD

LIPS_MEAN, LIPS_STD = get_lips_mean_std()
```

```
  0%|          | 0/40 [00:00<?, ?it/s]
```



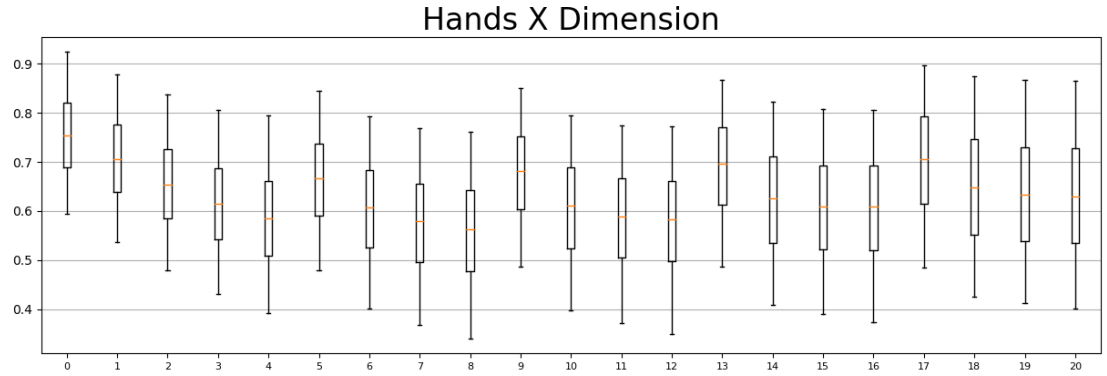


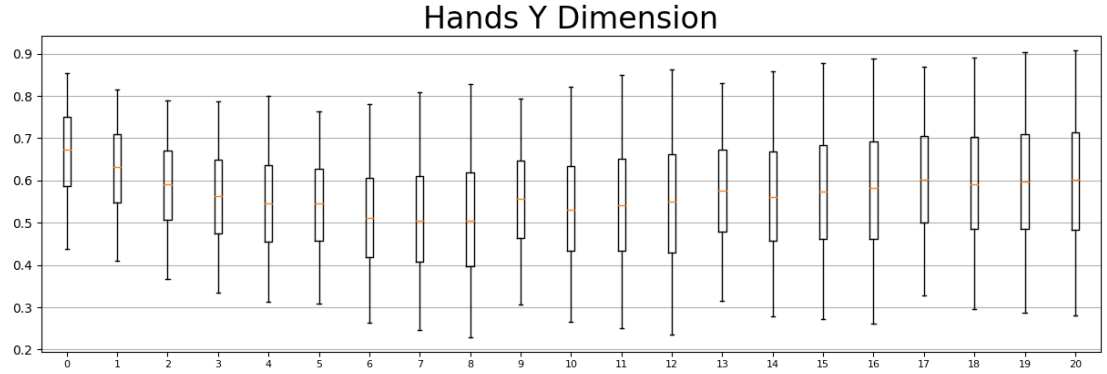


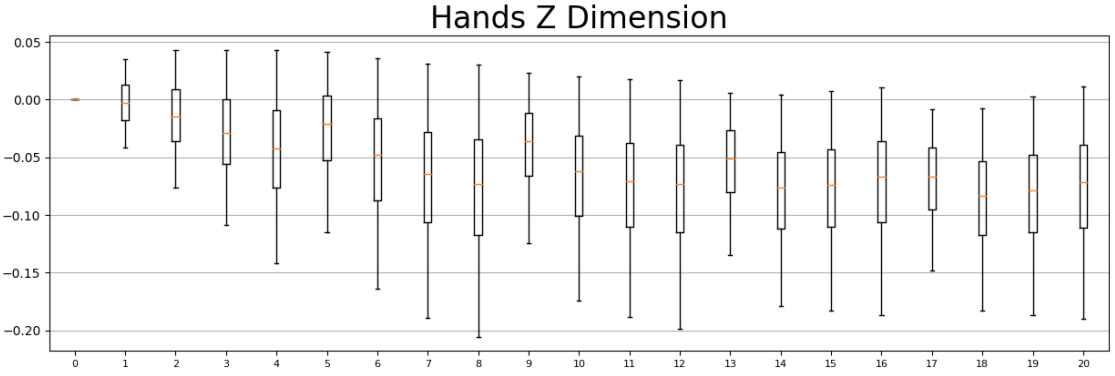
[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
  ↪gislr-tf-data-processing-transformer-training
def get_left_right_hand_mean_std():
    # LEFT HAND
    LEFT_HANDS_MEAN_X = np.zeros([LEFT_HAND_IDXS.size], dtype=np.float32)
    LEFT_HANDS_MEAN_Y = np.zeros([LEFT_HAND_IDXS.size], dtype=np.float32)
    LEFT_HANDS_STD_X = np.zeros([LEFT_HAND_IDXS.size], dtype=np.float32)
```

```
    LEFT_HANDS_STD_Y = np.zeros([LEFT_HAND_IDXS.size], dtype=np.float32)

    fig, axes = plt.subplots(3, 1, figsize=(15, N_DIMS*6))

    for col, ll in enumerate(tqdm( np.transpose(X_train[:,:,LEFT_HAND_IDXS],␣
 ↪[2,3,0,1]).reshape([LEFT_HAND_IDXS.size, N_DIMS, -1]) )):
        for dim, l in enumerate(ll):
            v = l[np.nonzero(l)]
            if dim == 0: # X
                LEFT_HANDS_MEAN_X[col] = v.mean()
                LEFT_HANDS_STD_X[col] = v.std()
            if dim == 1: # Y
                LEFT_HANDS_MEAN_Y[col] = v.mean()
                LEFT_HANDS_STD_Y[col] = v.std()
            # Plot
            axes[dim].boxplot(v, notch=False, showfliers=False,␣
 ↪positions=[col], whis=[5,95])

    for ax, dim_name in zip(axes, DIM_NAMES):
        ax.set_title(f'Hands {dim_name.upper()} Dimension', size=24)
        ax.tick_params(axis='x', labelsize=8)
        ax.grid(axis='y')

    plt.subplots_adjust(hspace=0.50)
    plt.show()

    LEFT_HANDS_MEAN = np.array([LEFT_HANDS_MEAN_X, LEFT_HANDS_MEAN_Y]).T
    LEFT_HANDS_STD = np.array([LEFT_HANDS_STD_X, LEFT_HANDS_STD_Y]).T

    return LEFT_HANDS_MEAN, LEFT_HANDS_STD

LEFT_HANDS_MEAN, LEFT_HANDS_STD = get_left_right_hand_mean_std()
```

```
  0%|          | 0/21 [00:00<?, ?it/s]
```



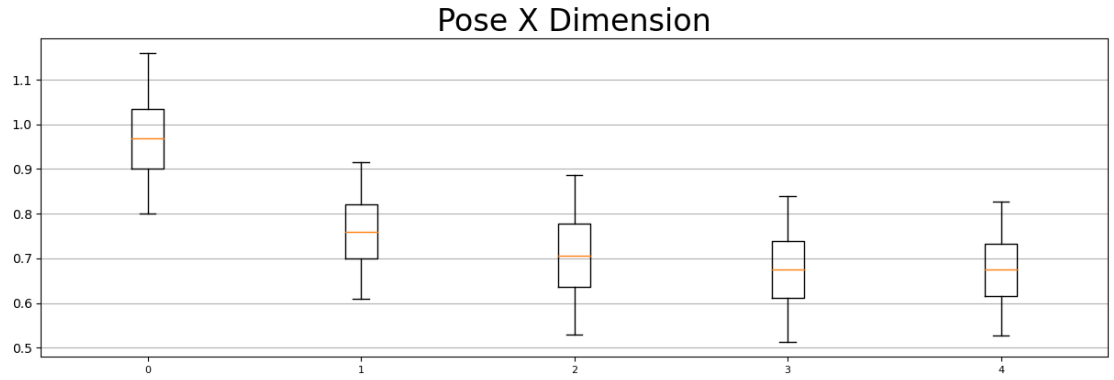


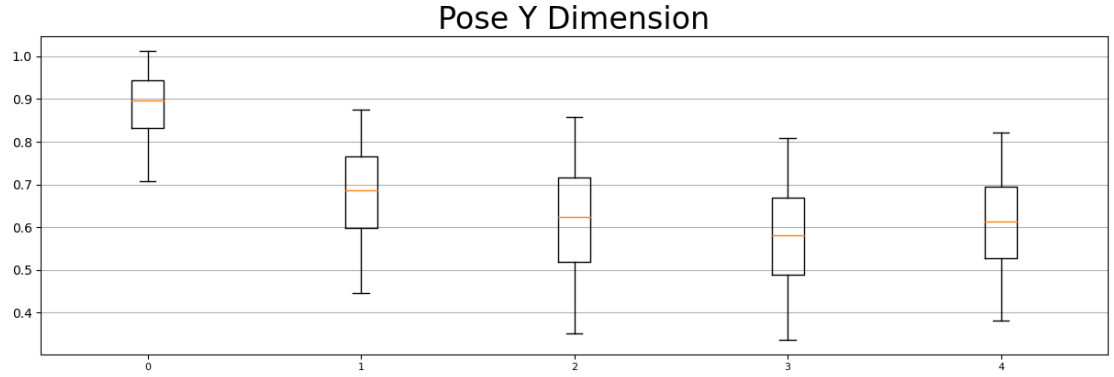


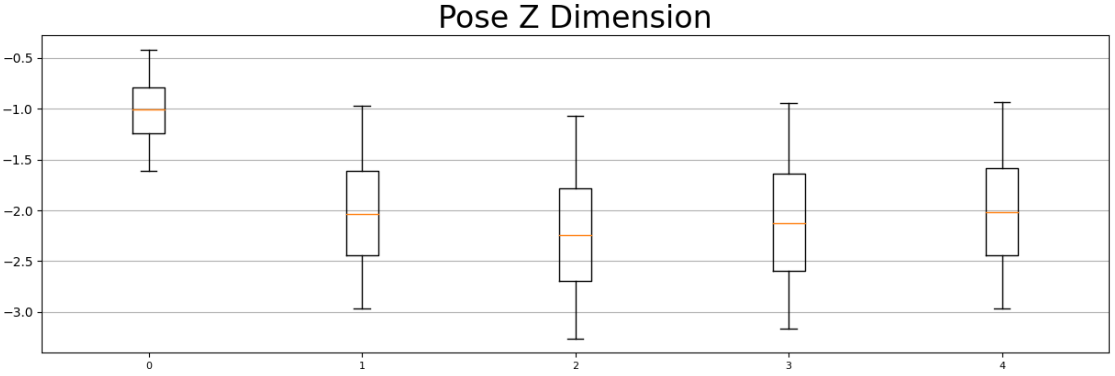
[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
  ↪gislr-tf-data-processing-transformer-training
def get_pose_mean_std():
    # POSE
    POSE_MEAN_X = np.zeros([POSE_IDXS.size], dtype=np.float32)
    POSE_MEAN_Y = np.zeros([POSE_IDXS.size], dtype=np.float32)
    POSE_STD_X = np.zeros([POSE_IDXS.size], dtype=np.float32)
```

```
    POSE_STD_Y = np.zeros([POSE_IDXS.size], dtype=np.float32)

    fig, axes = plt.subplots(3, 1, figsize=(15, N_DIMS*6))

    for col, ll in enumerate(tqdm( np.transpose(X_train[:,:,POSE_IDXS],␣
 ↪[2,3,0,1]).reshape([POSE_IDXS.size, N_DIMS, -1]) )):
        for dim, l in enumerate(ll):
            v = l[np.nonzero(l)]
            if dim == 0: # X
                POSE_MEAN_X[col] = v.mean()
                POSE_STD_X[col] = v.std()
            if dim == 1: # Y
                POSE_MEAN_Y[col] = v.mean()
                POSE_STD_Y[col] = v.std()

            axes[dim].boxplot(v, notch=False, showfliers=False,␣
 ↪positions=[col], whis=[5,95])

    for ax, dim_name in zip(axes, DIM_NAMES):
        ax.set_title(f'Pose {dim_name.upper()} Dimension', size=24)
        ax.tick_params(axis='x', labelsize=8)
        ax.grid(axis='y')

    plt.subplots_adjust(hspace=0.50)
    plt.show()

    POSE_MEAN = np.array([POSE_MEAN_X, POSE_MEAN_Y]).T
    POSE_STD = np.array([POSE_STD_X, POSE_STD_Y]).T

    return POSE_MEAN, POSE_STD

POSE_MEAN, POSE_STD = get_pose_mean_std()
```

```
  0%|          | 0/5 [00:00<?, ?it/s]
```







The attention mechanism is a key component in Transformer models, enabling the model to focus on different parts of the input sequence for each step of the output sequence. Attention enables the model to concentrate selectively on various segments of the input sequence for making predictions, rather than interpreting the entire sequence as a uniform-length vector. This feature has been crucial in the triumph of the transformer model, sparking extensive subsequent research and the development of numerous new models (Kumar, A. 2023). Wijkhuizen, M.'s custom transformer model deployed attention_mask in the Scaled Dot-Product function in a different way compared

to the classic transformer model in that this mask is applied in the Softmax step to selectively ignore or pay less attention to certain parts of the input, such as padding or irrelevant frames in a video sequence. Also, the Softmax layer was used instead of the Softmax function. The attention mechanism allows the model to focus on different parts of the input sequence dynamically, which is crucial for tasks like ASL recognition. In ASL, the importance of different landmarks can vary significantly across different signs. The multi-head attention mechanism is particularly well-suited to capture these varied dependencies.

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# based on: https://stackoverflow.com/questions/67342988/
 ↪verifying-the-implementation-of-multihead-attention-in-transformer
# replaced softmax with softmax layer to support masked softmax
def scaled_dot_product(q,k,v, softmax, attention_mask):
    #calculates Q . K(transpose)
    qkt = tf.matmul(q,k,transpose_b=True)
    #caculates scaling factor
    dk = tf.math.sqrt(tf.cast(q.shape[-1],dtype=tf.float32))
    scaled_qkt = qkt/dk
    softmax = softmax(scaled_qkt, mask=attention_mask)

    z = tf.matmul(softmax,v)
    #shape: (m,Tx,depth), same shape as q,k,v
    return z

class MultiHeadAttention(tf.keras.layers.Layer):
    def __init__(self,d_model,num_of_heads):
        super(MultiHeadAttention,self).__init__()
        self.d_model = d_model
        self.num_of_heads = num_of_heads
        self.depth = d_model//num_of_heads
        self.wq = [tf.keras.layers.Dense(self.depth) for i in␣
 ↪range(num_of_heads)]
        self.wk = [tf.keras.layers.Dense(self.depth) for i in␣
 ↪range(num_of_heads)]
        self.wv = [tf.keras.layers.Dense(self.depth) for i in␣
 ↪range(num_of_heads)]
        self.wo = tf.keras.layers.Dense(d_model)
        self.softmax = tf.keras.layers.Softmax()

    def call(self,x, attention_mask):

        multi_attn = []
        for i in range(self.num_of_heads):
            Q = self.wq[i](x)
            K = self.wk[i](x)
            V = self.wv[i](x)
```

```
            multi_attn.append(scaled_dot_product(Q,K,V, self.softmax,␣
↪attention_mask))

        multi_head = tf.concat(multi_attn,axis=-1)
        multi_head_attention = self.wo(multi_head)
        return multi_head_attention
```

Wijkhuizen, M.'s transformer model approach is a custom-modified transformer model similar similar the classic transformer model. There are custom changes to fit the ASL recognition tasks. This custom transformer only used a classic transformer encoder part for classification tasks, and it is the normal approach to only use the transformer encoder or decoder part alone. Besides the architecture part, there are two major customizations that Wijkhuizen, M. created that are different from the classic transformer model; one is the attention mechanism, and the other one is the embedding layer.

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
↪gislr-tf-data-processing-transformer-training
# Full Transformer
class Transformer(tf.keras.Model):
    def __init__(self, num_blocks):
        super(Transformer, self).__init__(name='transformer')
        self.num_blocks = num_blocks

    def build(self, input_shape):
        self.ln_1s = []
        self.mhas = []
        self.ln_2s = []
        self.mlps = []
        # Make Transformer Blocks
        for i in range(self.num_blocks):
            # Multi Head Attention
            self.mhas.append(MultiHeadAttention(UNITS, 8))
            # Multi Layer Perception
            self.mlps.append(tf.keras.Sequential([
                tf.keras.layers.Dense(UNITS * MLP_RATIO, activation=GELU,␣
↪kernel_initializer=INIT_GLOROT_UNIFORM),
                tf.keras.layers.Dropout(MLP_DROPOUT_RATIO),
                tf.keras.layers.Dense(UNITS,␣
↪kernel_initializer=INIT_HE_UNIFORM),
            ]))

    def call(self, x, attention_mask):
        # Iterate input over transformer blocks
        for mha, mlp in zip(self.mhas, self.mlps):
            x = x + mha(x, attention_mask)
            x = x + mlp(x)
```

```
        return x
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
class LandmarkEmbedding(tf.keras.Model):
    def __init__(self, units, name):
        super(LandmarkEmbedding, self).__init__(name=f'{name}_embedding')
        self.units = units

    def build(self, input_shape):
        # Embedding for missing landmark in frame, initizlied with zeros
        self.empty_embedding = self.add_weight(
            name=f'{self.name}_empty_embedding',
            shape=[self.units],
            initializer=INIT_ZEROS,
        )
        # Embedding
        self.dense = tf.keras.Sequential([
            tf.keras.layers.Dense(self.units, name=f'{self.name}_dense_1',␣
 ↪use_bias=False, kernel_initializer=INIT_GLOROT_UNIFORM),
            tf.keras.layers.Activation(GELU),
            tf.keras.layers.Dense(self.units, name=f'{self.name}_dense_2',␣
 ↪use_bias=False, kernel_initializer=INIT_HE_UNIFORM),
        ], name=f'{self.name}_dense')

    def call(self, x):
        return tf.where(
                # Checks whether landmark is missing in frame
                tf.reduce_sum(x, axis=2, keepdims=True) == 0,
                # If so, the empty embedding is used
                self.empty_embedding,
                # Otherwise the landmark data is embedded
                self.dense(x),
            )
```

Another customized part is the embedding layer. In the context of Transformer models, positional embeddings are crucial for providing information about the order or position of the elements in the input sequence (Huang, Z. et al., 2020). Compared to the classic transformer model, this ASL transformer model approach has an additional LandmarkEmbedding class that the Embedding class uses to deal with the embedding of individual landmarks. Each landmark type was embedded separately from lips, hand, and pose. The Embedding class is still handling the positional embedding.

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
class Embedding(tf.keras.Model):
    def __init__(self):
```

```
        super(Embedding, self).__init__()

    def get_diffs(self, l):
        S = l.shape[2]
        other = tf.expand_dims(l, 3)
        other = tf.repeat(other, S, axis=3)
        other = tf.transpose(other, [0,1,3,2])
        diffs = tf.expand_dims(l, 3) - other
        diffs = tf.reshape(diffs, [-1, INPUT_SIZE, S*S])
        return diffs

    def build(self, input_shape):
        # Positional Embedding, initialized with zeros
        self.positional_embedding = tf.keras.layers.Embedding(INPUT_SIZE+1,␣
↪UNITS, embeddings_initializer=INIT_ZEROS)
        # Embedding layer for Landmarks
        self.lips_embedding = LandmarkEmbedding(LIPS_UNITS, 'lips')
        self.left_hand_embedding = LandmarkEmbedding(HANDS_UNITS, 'left_hand')
        self.pose_embedding = LandmarkEmbedding(POSE_UNITS, 'pose')
        # Landmark Weights
        self.landmark_weights = tf.Variable(tf.zeros([3], dtype=tf.float32),␣
↪name='landmark_weights')
        # Fully Connected Layers for combined landmarks
        self.fc = tf.keras.Sequential([
            tf.keras.layers.Dense(UNITS, name='fully_connected_1',␣
↪use_bias=False, kernel_initializer=INIT_GLOROT_UNIFORM),
            tf.keras.layers.Activation(GELU),
            tf.keras.layers.Dense(UNITS, name='fully_connected_2',␣
↪use_bias=False, kernel_initializer=INIT_HE_UNIFORM),
        ], name='fc')


    def call(self, lips0, left_hand0, pose0, non_empty_frame_idxs,␣
↪training=False):
        # Lips
        lips_embedding = self.lips_embedding(lips0)
        # Left Hand
        left_hand_embedding = self.left_hand_embedding(left_hand0)
        # Pose
        pose_embedding = self.pose_embedding(pose0)
        # Merge Embeddings of all landmarks with mean pooling
        x = tf.stack((
            lips_embedding, left_hand_embedding, pose_embedding,
        ), axis=3)
        x = x * tf.nn.softmax(self.landmark_weights)
        x = tf.reduce_sum(x, axis=3)
        # Fully Connected Layers
```

```
        x = self.fc(x)
        # Add Positional Embedding
        max_frame_idxs = tf.clip_by_value(
                tf.reduce_max(non_empty_frame_idxs, axis=1, keepdims=True),
                1,
                np.PINF,
            )
        normalised_non_empty_frame_idxs = tf.where(
            tf.math.equal(non_empty_frame_idxs, -1.0),
            INPUT_SIZE,
            tf.cast(
                non_empty_frame_idxs / max_frame_idxs * INPUT_SIZE,
                tf.int32,
            ),
        )
        x = x + self.positional_embedding(normalised_non_empty_frame_idxs)

        return x
```

[ ]:
```
# source:: https://stackoverflow.com/questions/60689185/
 ↪label-smoothing-for-sparse-categorical-crossentropy
def scce_with_ls(y_true, y_pred):
    # One Hot Encode Sparsely Encoded Target Sign
    y_true = tf.cast(y_true, tf.int32)
    y_true = tf.one_hot(y_true, NUM_CLASSES, axis=1)
    y_true = tf.squeeze(y_true, axis=2)
    # Categorical Crossentropy with native label smoothing support
    return tf.keras.losses.categorical_crossentropy(y_true, y_pred,␣
 ↪label_smoothing=0.25)
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
def get_model():
    # Inputs
    frames = tf.keras.layers.Input([INPUT_SIZE, N_COLS, N_DIMS], dtype=tf.
 ↪float32, name='frames')
    non_empty_frame_idxs = tf.keras.layers.Input([INPUT_SIZE], dtype=tf.
 ↪float32, name='non_empty_frame_idxs')
    # Padding Mask
    mask0 = tf.cast(tf.math.not_equal(non_empty_frame_idxs, -1), tf.float32)
    mask0 = tf.expand_dims(mask0, axis=2)
    # Random Frame Masking
    mask = tf.where(
        (tf.random.uniform(tf.shape(mask0)) > 0.25) & tf.math.not_equal(mask0,␣
 ↪0.0),
        1.0,
        0.0,
```

```
    )
    # Correct Samples Which are all masked now...
    mask = tf.where(
        tf.math.equal(tf.reduce_sum(mask, axis=[1,2], keepdims=True), 0.0),
        mask0,
        mask,
    )


    """
        left_hand: 468:489
        pose: 489:522
        right_hand: 522:543
    """
    x = frames
    x = tf.slice(x, [0,0,0,0], [-1,INPUT_SIZE, N_COLS, 2])
    # LIPS
    lips = tf.slice(x, [0,0,LIPS_START,0], [-1,INPUT_SIZE, 40, 2])
    lips = tf.where(
            tf.math.equal(lips, 0.0),
            0.0,
            (lips - LIPS_MEAN) / LIPS_STD,
        )
    # LEFT HAND
    left_hand = tf.slice(x, [0,0,40,0], [-1,INPUT_SIZE, 21, 2])
    left_hand = tf.where(
            tf.math.equal(left_hand, 0.0),
            0.0,
            (left_hand - LEFT_HANDS_MEAN) / LEFT_HANDS_STD,
        )
    # POSE
    pose = tf.slice(x, [0,0,61,0], [-1,INPUT_SIZE, 5, 2])
    pose = tf.where(
            tf.math.equal(pose, 0.0),
            0.0,
            (pose - POSE_MEAN) / POSE_STD,
        )

    # Flatten
    lips = tf.reshape(lips, [-1, INPUT_SIZE, 40*2])
    left_hand = tf.reshape(left_hand, [-1, INPUT_SIZE, 21*2])
    pose = tf.reshape(pose, [-1, INPUT_SIZE, 5*2])

    # Embedding
    x = Embedding()(lips, left_hand, pose, non_empty_frame_idxs)

    # Encoder Transformer Blocks
```

```
    x = Transformer(NUM_BLOCKS)(x, mask)

    # Pooling
    x = tf.reduce_sum(x * mask, axis=1) / tf.reduce_sum(mask, axis=1)
    # Classifier Dropout
    x = tf.keras.layers.Dropout(CLASSIFIER_DROPOUT_RATIO)(x)
    # Classification Layer
    x = tf.keras.layers.Dense(NUM_CLASSES, activation=tf.keras.activations.
 ↪softmax, kernel_initializer=INIT_GLOROT_UNIFORM)(x)

    outputs = x

    # Create Tensorflow Model
    model = tf.keras.models.Model(inputs=[frames, non_empty_frame_idxs],␣
 ↪outputs=outputs)

    # Sparse Categorical Cross Entropy With Label Smoothing
    loss = scce_with_ls

    # Adam Optimizer with weight decay
    optimizer = tfa.optimizers.AdamW(learning_rate=1e-3, weight_decay=1e-5,␣
 ↪clipnorm=1.0)

    # TopK Metrics
    metrics = [
        tf.keras.metrics.SparseCategoricalAccuracy(name='acc'),
        tf.keras.metrics.SparseTopKCategoricalAccuracy(k=5, name='top_5_acc'),
        tf.keras.metrics.SparseTopKCategoricalAccuracy(k=10, name='top_10_acc'),
    ]

    model.compile(loss=loss, optimizer=optimizer, metrics=metrics)

    return model
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
tf.keras.backend.clear_session()

model = get_model()
```

[ ]:
```
# Plot model summary
model.summary(expand_nested=True)
```

```
Model: "model"
_________________________________________________________________________________
__________________
 Layer (type)                Output Shape              Param #   Connected to
```

```
==========================================================================================
 non_empty_frame_idxs (Inpu  [(None, 64)]                0         []
 tLayer)

 tf.math.not_equal (TFOpLam  (None, 64)                  0
['non_empty_frame_idxs[0][0]']
 bda)

 tf.cast (TFOpLambda)        (None, 64)                  0
['tf.math.not_equal[0][0]']

 tf.expand_dims (TFOpLambda  (None, 64, 1)               0
['tf.cast[0][0]']
 )

 frames (InputLayer)         [(None, 64, 66, 3)]         0         []

 tf.compat.v1.shape (TFOpLa  (3,)                        0
['tf.expand_dims[0][0]']
 mbda)

 tf.slice (TFOpLambda)       (None, 64, 66, 2)           0
['frames[0][0]']

 tf.random.uniform (TFOpLam  (None, 64, 1)               0
['tf.compat.v1.shape[0][0]']
 bda)

 tf.slice_1 (TFOpLambda)     (None, 64, 40, 2)           0
['tf.slice[0][0]']

 tf.slice_2 (TFOpLambda)     (None, 64, 21, 2)           0
['tf.slice[0][0]']

 tf.slice_3 (TFOpLambda)     (None, 64, 5, 2)            0
['tf.slice[0][0]']

 tf.math.greater (TFOpLambd  (None, 64, 1)               0
['tf.random.uniform[0][0]']
 a)

 tf.math.not_equal_1 (TFOpL  (None, 64, 1)               0
['tf.expand_dims[0][0]']
 ambda)

 tf.math.subtract (TFOpLamb  (None, 64, 40, 2)           0
['tf.slice_1[0][0]']
```

```
 da)

 tf.math.subtract_1 (TFOpLa  (None, 64, 21, 2)           0
['tf.slice_2[0][0]']
 mbda)

 tf.math.subtract_2 (TFOpLa  (None, 64, 5, 2)            0
['tf.slice_3[0][0]']
 mbda)

 tf.math.logical_and (TFOpL  (None, 64, 1)               0
['tf.math.greater[0][0]',
 ambda)
'tf.math.not_equal_1[0][0]']

 tf.math.equal_1 (TFOpLambd  (None, 64, 40, 2)           0
['tf.slice_1[0][0]']
 a)

 tf.math.truediv (TFOpLambd  (None, 64, 40, 2)           0
['tf.math.subtract[0][0]']
 a)

 tf.math.equal_2 (TFOpLambd  (None, 64, 21, 2)           0
['tf.slice_2[0][0]']
 a)

 tf.math.truediv_1 (TFOpLam  (None, 64, 21, 2)           0
['tf.math.subtract_1[0][0]']
 bda)

 tf.math.equal_3 (TFOpLambd  (None, 64, 5, 2)            0
['tf.slice_3[0][0]']
 a)

 tf.math.truediv_2 (TFOpLam  (None, 64, 5, 2)            0
['tf.math.subtract_2[0][0]']
 bda)

 tf.where (TFOpLambda)       (None, 64, 1)               0
['tf.math.logical_and[0][0]']

 tf.where_2 (TFOpLambda)     (None, 64, 40, 2)           0
['tf.math.equal_1[0][0]',
'tf.math.truediv[0][0]']

 tf.where_3 (TFOpLambda)     (None, 64, 21, 2)           0
['tf.math.equal_2[0][0]',
```

```
'tf.math.truediv_1[0][0]']

 tf.where_4 (TFOpLambda)     (None, 64, 5, 2)            0
['tf.math.equal_3[0][0]',
'tf.math.truediv_2[0][0]']

 tf.math.reduce_sum (TFOpLa  (None, 1, 1)                0
['tf.where[0][0]']
 mbda)

 tf.reshape (TFOpLambda)     (None, 64, 80)              0
['tf.where_2[0][0]']

 tf.reshape_1 (TFOpLambda)   (None, 64, 42)              0
['tf.where_3[0][0]']

 tf.reshape_2 (TFOpLambda)   (None, 64, 10)              0
['tf.where_4[0][0]']

 tf.math.equal (TFOpLambda)  (None, 1, 1)                0
['tf.math.reduce_sum[0][0]']

 embedding (Embedding)       (None, 64, 512)             986243
['tf.reshape[0][0]',
'tf.reshape_1[0][0]',
'tf.reshape_2[0][0]',
'non_empty_frame_idxs[0][0]']
|-------------------------------------------------------------------------------
-----------------|
| embedding (Embedding)      multiple                    33280     []
|
|
|
| lips_embedding (LandmarkE  multiple                    178560    []
|
| mbedding)
|
||-----------------------------------------------------------------------------
----------------||
|| lips_embedding_dense (Se  (None, 64, 384)             178176    []
||
|| quential)
||
|||---------------------------------------------------------------------------
---------------|||
||| lips_embedding_dense_1   (None, 64, 384)             30720     []
|||
||| (Dense)
```

```
|||
|||
|||
||| activation_1 (Activatio  (None, 64, 384)              0         []
|||
||| n)
|||
|||
|||
||| lips_embedding_dense_2   (None, 64, 384)              147456    []
|||
||| (Dense)
|||
||-------------------------------------------------------------------------------
----------------||
|-------------------------------------------------------------------------------
-----------------|
| left_hand_embedding (Land  multiple                    163968    []
|
| markEmbedding)
|
||-------------------------------------------------------------------------------
----------------||
|| left_hand_embedding_dens  (None, 64, 384)              163584    []
||
|| e (Sequential)
||
|||-------------------------------------------------------------------------------
---------------|||
||| left_hand_embedding_den  (None, 64, 384)              16128     []
|||
||| se_1 (Dense)
|||
|||
|||
||| activation_2 (Activatio  (None, 64, 384)              0         []
|||
||| n)
|||
|||
|||
||| left_hand_embedding_den  (None, 64, 384)              147456    []
|||
||| se_2 (Dense)
|||
||-------------------------------------------------------------------------------
----------------||
|-------------------------------------------------------------------------------
```

```
-----------------|
| pose_embedding (LandmarkE  multiple                    151680    []
|
| mbedding)
|
||--------------------------------------------------------------------------
----------------||
|| pose_embedding_dense (Se  (None, 64, 384)             151296    []
||
|| quential)
||
|||------------------------------------------------------------------------
---------------|||
||| pose_embedding_dense_1   (None, 64, 384)             3840      []
|||
||| (Dense)
|||
|||
|||
||| activation_3 (Activatio  (None, 64, 384)             0         []
|||
||| n)
|||
|||
|||
||| pose_embedding_dense_2   (None, 64, 384)             147456    []
|||
||| (Dense)
|||
||--------------------------------------------------------------------------
----------------||
|--------------------------------------------------------------------------
-----------------|
| fc (Sequential)            (None, 64, 512)             458752    []
|
||--------------------------------------------------------------------------
----------------||
|| fully_connected_1 (Dense  (None, 64, 512)             196608    []
||
|| )
||
||
||
|| activation (Activation)   (None, 64, 512)             0         []
||
||
||
|| fully_connected_2 (Dense  (None, 64, 512)             262144    []
```

```
||
|| )
||
|-----------------------------------------------------------------------------
-----------------|
-----------------------------------------------------------------------------
-----------------
 tf.where_1 (TFOpLambda)     (None, 64, 1)               0
['tf.math.equal[0][0]',
'tf.expand_dims[0][0]',
'tf.where[0][0]']

 transformer (Transformer)   (None, 64, 512)             4201472
['embedding[0][0]',
'tf.where_1[0][0]']
|-----------------------------------------------------------------------------
-----------------|
| multi_head_attention (Mul  multiple                    1050624   []
|
| tiHeadAttention)
|
|
|
| multi_head_attention_1 (M  multiple                    1050624   []
|
| ultiHeadAttention)
|
|
|
| sequential (Sequential)    (None, 64, 512)             1050112   []
|
||----------------------------------------------------------------------------
----------------||
|| dense_25 (Dense)          (None, 64, 1024)            525312    []
||
||
||
|| dropout (Dropout)         (None, 64, 1024)            0         []
||
||
||
|| dense_26 (Dense)          (None, 64, 512)             524800    []
||
|-----------------------------------------------------------------------------
-----------------|
| sequential_1 (Sequential)  (None, 64, 512)             1050112   []
|
||-----------------------------------------------------------------------------
```

```
----------------||
|| dense_52 (Dense)          (None, 64, 1024)             525312    []
||
||
||
|| dropout_1 (Dropout)       (None, 64, 1024)             0         []
||
||
||
|| dense_53 (Dense)          (None, 64, 512)              524800    []
||
|-------------------------------------------------------------------------------
-----------------|
-------------------------------------------------------------------------------
------------------
 tf.math.multiply (TFOpLamb  (None, 64, 512)              0
['transformer[0][0]',
 da)
'tf.where_1[0][0]']

 tf.math.reduce_sum_1 (TFOp  (None, 512)                  0
['tf.math.multiply[0][0]']
 Lambda)

 tf.math.reduce_sum_2 (TFOp  (None, 1)                    0
['tf.where_1[0][0]']
 Lambda)

 tf.math.truediv_3 (TFOpLam  (None, 512)                  0
['tf.math.reduce_sum_1[0][0]',
 bda)
'tf.math.reduce_sum_2[0][0]']

 dropout (Dropout)           (None, 512)                  0
['tf.math.truediv_3[0][0]']

 dense (Dense)               (None, 250)                  128250
['dropout[0][0]']

===============================================================================
==================
Total params: 5315965 (20.28 MB)
Trainable params: 5315965 (20.28 MB)
Non-trainable params: 0 (0.00 Byte)
-------------------------------------------------------------------------------
------------------
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
def get_train_batch_all_signs(X, y, NON_EMPTY_FRAME_IDXS, n=BATCH_ALL_SIGNS_N):
    # Arrays to store batch in
    X_batch = np.zeros([NUM_CLASSES*n, INPUT_SIZE, N_COLS, N_DIMS], dtype=np.
 ↪float32)
    y_batch = np.arange(0, NUM_CLASSES, step=1/n, dtype=np.float32).astype(np.
 ↪int64)
    non_empty_frame_idxs_batch = np.zeros([NUM_CLASSES*n, INPUT_SIZE], dtype=np.
 ↪float32)

    # Dictionary mapping ordinally encoded sign to corresponding sample indices
    CLASS2IDXS = {}
    for i in range(NUM_CLASSES):
        CLASS2IDXS[i] = np.argwhere(y == i).squeeze().astype(np.int32)

    while True:
        # Fill batch arrays
        for i in range(NUM_CLASSES):
            idxs = np.random.choice(CLASS2IDXS[i], n)
            X_batch[i*n:(i+1)*n] = X[idxs]
            non_empty_frame_idxs_batch[i*n:(i+1)*n] = NON_EMPTY_FRAME_IDXS[idxs]

        yield { 'frames': X_batch, 'non_empty_frame_idxs':␣
 ↪non_empty_frame_idxs_batch }, y_batch
```

[ ]:
```
# Code From https://www.kaggle.com/code/markwijkhuizen/
 ↪gislr-tf-data-processing-transformer-training
# Actual Training
history = model.fit(
            x=get_train_batch_all_signs(X_train, y_train,␣
 ↪NON_EMPTY_FRAME_IDXS_TRAIN),
            steps_per_epoch=len(X_train) // (NUM_CLASSES * BATCH_ALL_SIGNS_N),
            epochs=N_EPOCHS,
            batch_size=BATCH_SIZE,
        )
```

```
Epoch 1/100
80/80 [==============================] - 34s 213ms/step - loss: 4.3454 - acc:
0.2691 - top_5_acc: 0.5258 - top_10_acc: 0.6316
Epoch 2/100
80/80 [==============================] - 17s 212ms/step - loss: 3.3600 - acc:
0.5616 - top_5_acc: 0.8160 - top_10_acc: 0.8755
Epoch 3/100
80/80 [==============================] - 17s 213ms/step - loss: 3.0562 - acc:
0.6665 - top_5_acc: 0.8765 - top_10_acc: 0.9160
Epoch 4/100
```

```
80/80 [==============================] - 17s 212ms/step - loss: 2.9035 - acc:
0.7227 - top_5_acc: 0.9030 - top_10_acc: 0.9325
Epoch 5/100
80/80 [==============================] - 17s 212ms/step - loss: 2.8028 - acc:
0.7592 - top_5_acc: 0.9164 - top_10_acc: 0.9422
Epoch 6/100
80/80 [==============================] - 17s 212ms/step - loss: 2.7248 - acc:
0.7879 - top_5_acc: 0.9294 - top_10_acc: 0.9517
Epoch 7/100
80/80 [==============================] - 17s 212ms/step - loss: 2.6656 - acc:
0.8100 - top_5_acc: 0.9388 - top_10_acc: 0.9578
Epoch 8/100
80/80 [==============================] - 17s 213ms/step - loss: 2.6164 - acc:
0.8279 - top_5_acc: 0.9471 - top_10_acc: 0.9636
Epoch 9/100
80/80 [==============================] - 17s 212ms/step - loss: 2.5814 - acc:
0.8413 - top_5_acc: 0.9530 - top_10_acc: 0.9684
Epoch 10/100
80/80 [==============================] - 17s 213ms/step - loss: 2.5529 - acc:
0.8528 - top_5_acc: 0.9582 - top_10_acc: 0.9721
Epoch 11/100
80/80 [==============================] - 17s 212ms/step - loss: 2.5209 - acc:
0.8652 - top_5_acc: 0.9637 - top_10_acc: 0.9753
Epoch 12/100
80/80 [==============================] - 17s 212ms/step - loss: 2.4854 - acc:
0.8784 - top_5_acc: 0.9682 - top_10_acc: 0.9788
Epoch 13/100
80/80 [==============================] - 17s 212ms/step - loss: 2.4557 - acc:
0.8899 - top_5_acc: 0.9715 - top_10_acc: 0.9814
Epoch 14/100
80/80 [==============================] - 17s 212ms/step - loss: 2.4267 - acc:
0.9001 - top_5_acc: 0.9750 - top_10_acc: 0.9841
Epoch 15/100
80/80 [==============================] - 17s 212ms/step - loss: 2.4016 - acc:
0.9093 - top_5_acc: 0.9784 - top_10_acc: 0.9862
Epoch 16/100
80/80 [==============================] - 17s 213ms/step - loss: 2.3756 - acc:
0.9175 - top_5_acc: 0.9812 - top_10_acc: 0.9879
Epoch 17/100
80/80 [==============================] - 17s 213ms/step - loss: 2.3534 - acc:
0.9265 - top_5_acc: 0.9839 - top_10_acc: 0.9898
Epoch 18/100
80/80 [==============================] - 17s 212ms/step - loss: 2.3355 - acc:
0.9319 - top_5_acc: 0.9859 - top_10_acc: 0.9910
Epoch 19/100
80/80 [==============================] - 17s 213ms/step - loss: 2.3125 - acc:
0.9420 - top_5_acc: 0.9882 - top_10_acc: 0.9927
Epoch 20/100
```

```
80/80 [==============================] - 17s 212ms/step - loss: 2.3044 - acc:
0.9432 - top_5_acc: 0.9892 - top_10_acc: 0.9937
Epoch 21/100
80/80 [==============================] - 17s 213ms/step - loss: 2.2896 - acc:
0.9491 - top_5_acc: 0.9905 - top_10_acc: 0.9948
Epoch 22/100
80/80 [==============================] - 17s 213ms/step - loss: 2.2773 - acc:
0.9524 - top_5_acc: 0.9914 - top_10_acc: 0.9948
Epoch 23/100
80/80 [==============================] - 17s 212ms/step - loss: 2.2823 - acc:
0.9523 - top_5_acc: 0.9921 - top_10_acc: 0.9953
Epoch 24/100
80/80 [==============================] - 17s 213ms/step - loss: 2.2719 - acc:
0.9547 - top_5_acc: 0.9926 - top_10_acc: 0.9959
Epoch 25/100
80/80 [==============================] - 17s 212ms/step - loss: 2.2757 - acc:
0.9541 - top_5_acc: 0.9927 - top_10_acc: 0.9959
Epoch 26/100
80/80 [==============================] - 17s 213ms/step - loss: 2.2646 - acc:
0.9575 - top_5_acc: 0.9941 - top_10_acc: 0.9966
Epoch 27/100
80/80 [==============================] - 17s 212ms/step - loss: 2.2591 - acc:
0.9590 - top_5_acc: 0.9944 - top_10_acc: 0.9970
Epoch 28/100
80/80 [==============================] - 17s 212ms/step - loss: 2.2620 - acc:
0.9582 - top_5_acc: 0.9940 - top_10_acc: 0.9967
Epoch 29/100
80/80 [==============================] - 17s 212ms/step - loss: 2.2553 - acc:
0.9603 - top_5_acc: 0.9952 - top_10_acc: 0.9973
Epoch 30/100
80/80 [==============================] - 17s 212ms/step - loss: 2.2412 - acc:
0.9642 - top_5_acc: 0.9955 - top_10_acc: 0.9980
Epoch 31/100
80/80 [==============================] - 17s 212ms/step - loss: 2.2417 - acc:
0.9638 - top_5_acc: 0.9961 - top_10_acc: 0.9982
Epoch 32/100
80/80 [==============================] - 17s 212ms/step - loss: 2.2300 - acc:
0.9687 - top_5_acc: 0.9965 - top_10_acc: 0.9983
Epoch 33/100
80/80 [==============================] - 17s 213ms/step - loss: 2.2245 - acc:
0.9690 - top_5_acc: 0.9968 - top_10_acc: 0.9985
Epoch 34/100
80/80 [==============================] - 17s 213ms/step - loss: 2.2157 - acc:
0.9719 - top_5_acc: 0.9974 - top_10_acc: 0.9989
Epoch 35/100
80/80 [==============================] - 17s 213ms/step - loss: 2.2132 - acc:
0.9727 - top_5_acc: 0.9979 - top_10_acc: 0.9990
Epoch 36/100
```

```
80/80 [==============================] - 17s 212ms/step - loss: 2.2120 - acc:
0.9730 - top_5_acc: 0.9980 - top_10_acc: 0.9991
Epoch 37/100
80/80 [==============================] - 17s 213ms/step - loss: 2.2113 - acc:
0.9730 - top_5_acc: 0.9976 - top_10_acc: 0.9991
Epoch 38/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1991 - acc:
0.9768 - top_5_acc: 0.9981 - top_10_acc: 0.9993
Epoch 39/100
80/80 [==============================] - 17s 212ms/step - loss: 2.2091 - acc:
0.9746 - top_5_acc: 0.9982 - top_10_acc: 0.9993
Epoch 40/100
80/80 [==============================] - 17s 213ms/step - loss: 2.2064 - acc:
0.9745 - top_5_acc: 0.9981 - top_10_acc: 0.9993
Epoch 41/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1985 - acc:
0.9768 - top_5_acc: 0.9986 - top_10_acc: 0.9995
Epoch 42/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1908 - acc:
0.9786 - top_5_acc: 0.9984 - top_10_acc: 0.9994
Epoch 43/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1864 - acc:
0.9797 - top_5_acc: 0.9989 - top_10_acc: 0.9996
Epoch 44/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1894 - acc:
0.9793 - top_5_acc: 0.9987 - top_10_acc: 0.9995
Epoch 45/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1851 - acc:
0.9804 - top_5_acc: 0.9987 - top_10_acc: 0.9995
Epoch 46/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1856 - acc:
0.9799 - top_5_acc: 0.9989 - top_10_acc: 0.9996
Epoch 47/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1821 - acc:
0.9809 - top_5_acc: 0.9989 - top_10_acc: 0.9996
Epoch 48/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1774 - acc:
0.9813 - top_5_acc: 0.9990 - top_10_acc: 0.9995
Epoch 49/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1757 - acc:
0.9830 - top_5_acc: 0.9990 - top_10_acc: 0.9996
Epoch 50/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1845 - acc:
0.9802 - top_5_acc: 0.9990 - top_10_acc: 0.9995
Epoch 51/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1786 - acc:
0.9818 - top_5_acc: 0.9993 - top_10_acc: 0.9998
Epoch 52/100
```

```
80/80 [==============================] - 17s 212ms/step - loss: 2.1759 - acc:
0.9815 - top_5_acc: 0.9990 - top_10_acc: 0.9996
Epoch 53/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1649 - acc:
0.9839 - top_5_acc: 0.9991 - top_10_acc: 0.9996
Epoch 54/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1734 - acc:
0.9827 - top_5_acc: 0.9992 - top_10_acc: 0.9997
Epoch 55/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1685 - acc:
0.9835 - top_5_acc: 0.9991 - top_10_acc: 0.9996
Epoch 56/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1836 - acc:
0.9807 - top_5_acc: 0.9991 - top_10_acc: 0.9997
Epoch 57/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1731 - acc:
0.9830 - top_5_acc: 0.9992 - top_10_acc: 0.9998
Epoch 58/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1624 - acc:
0.9852 - top_5_acc: 0.9994 - top_10_acc: 0.9998
Epoch 59/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1498 - acc:
0.9869 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 60/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1421 - acc:
0.9886 - top_5_acc: 0.9995 - top_10_acc: 0.9999
Epoch 61/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1522 - acc:
0.9870 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 62/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1498 - acc:
0.9872 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 63/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1590 - acc:
0.9853 - top_5_acc: 0.9994 - top_10_acc: 0.9998
Epoch 64/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1571 - acc:
0.9859 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 65/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1620 - acc:
0.9841 - top_5_acc: 0.9995 - top_10_acc: 0.9999
Epoch 66/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1584 - acc:
0.9857 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 67/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1479 - acc:
0.9876 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 68/100
```

```
80/80 [==============================] - 17s 213ms/step - loss: 2.1402 - acc:
0.9890 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 69/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1360 - acc:
0.9895 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 70/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1389 - acc:
0.9892 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 71/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1612 - acc:
0.9847 - top_5_acc: 0.9993 - top_10_acc: 0.9997
Epoch 72/100
80/80 [==============================] - 17s 214ms/step - loss: 2.1525 - acc:
0.9873 - top_5_acc: 0.9995 - top_10_acc: 0.9999
Epoch 73/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1473 - acc:
0.9869 - top_5_acc: 0.9995 - top_10_acc: 0.9999
Epoch 74/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1393 - acc:
0.9890 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 75/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1378 - acc:
0.9889 - top_5_acc: 0.9996 - top_10_acc: 0.9998
Epoch 76/100
80/80 [==============================] - 17s 214ms/step - loss: 2.1309 - acc:
0.9899 - top_5_acc: 0.9998 - top_10_acc: 0.9999
Epoch 77/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1278 - acc:
0.9903 - top_5_acc: 0.9998 - top_10_acc: 1.0000
Epoch 78/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1444 - acc:
0.9880 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 79/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1399 - acc:
0.9887 - top_5_acc: 0.9997 - top_10_acc: 0.9999
Epoch 80/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1372 - acc:
0.9897 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 81/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1375 - acc:
0.9893 - top_5_acc: 0.9998 - top_10_acc: 0.9999
Epoch 82/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1417 - acc:
0.9879 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 83/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1404 - acc:
0.9891 - top_5_acc: 0.9996 - top_10_acc: 0.9998
Epoch 84/100
```

```
80/80 [==============================] - 17s 212ms/step - loss: 2.1333 - acc:
0.9894 - top_5_acc: 0.9998 - top_10_acc: 0.9999
Epoch 85/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1256 - acc:
0.9911 - top_5_acc: 0.9997 - top_10_acc: 1.0000
Epoch 86/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1319 - acc:
0.9896 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 87/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1290 - acc:
0.9902 - top_5_acc: 0.9998 - top_10_acc: 1.0000
Epoch 88/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1353 - acc:
0.9889 - top_5_acc: 0.9997 - top_10_acc: 0.9999
Epoch 89/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1451 - acc:
0.9873 - top_5_acc: 0.9995 - top_10_acc: 0.9998
Epoch 90/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1329 - acc:
0.9899 - top_5_acc: 0.9997 - top_10_acc: 0.9999
Epoch 91/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1321 - acc:
0.9898 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 92/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1384 - acc:
0.9879 - top_5_acc: 0.9996 - top_10_acc: 0.9998
Epoch 93/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1364 - acc:
0.9889 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 94/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1353 - acc:
0.9893 - top_5_acc: 0.9996 - top_10_acc: 0.9999
Epoch 95/100
80/80 [==============================] - 17s 212ms/step - loss: 2.1267 - acc:
0.9903 - top_5_acc: 0.9997 - top_10_acc: 0.9999
Epoch 96/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1231 - acc:
0.9912 - top_5_acc: 0.9997 - top_10_acc: 0.9998
Epoch 97/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1176 - acc:
0.9926 - top_5_acc: 0.9998 - top_10_acc: 0.9999
Epoch 98/100
80/80 [==============================] - 17s 214ms/step - loss: 2.1271 - acc:
0.9907 - top_5_acc: 0.9996 - top_10_acc: 0.9998
Epoch 99/100
80/80 [==============================] - 17s 213ms/step - loss: 2.1428 - acc:
0.9881 - top_5_acc: 0.9995 - top_10_acc: 0.9999
Epoch 100/100
```

```
80/80 [==============================] - 17s 213ms/step - loss: 2.1362 - acc:
0.9885 - top_5_acc: 0.9996 - top_10_acc: 0.9999
```

[ ]:
```
y_val_pred = model.predict({ 'frames': X_val, 'non_empty_frame_idxs':␣
↪NON_EMPTY_FRAME_IDXS_VAL }, verbose=2).argmax(axis=1)
```

```
446/446 - 6s - 6s/epoch - 12ms/step
```

[ ]:
```
y_val_pred.shape
```

[ ]:
```
(14248,)
```

[ ]:
```
y_val_pred
```

[ ]:
```
array([ 47,  30,  54, …, 145, 142, 238])
```

[ ]:
```
y_val
```

[ ]:
```
array([ 47,  30,  54, …,  79, 142, 238], dtype=int32)
```

[ ]:
```
import json

signmap_sub_dir = 'sign_to_prediction_index_map.json'
signmap_full_file_path = os.path.join(googledrive_dir, signmap_sub_dir)
# Load the sign to index mapping
with open(signmap_full_file_path, 'r') as file:
    sign_to_index = json.load(file)
```

[ ]:
```
sign_to_index
```

[ ]:
```
{'TV': 0,
 'after': 1,
 'airplane': 2,
 'all': 3,
 'alligator': 4,
 'animal': 5,
 'another': 6,
 'any': 7,
 'apple': 8,
 'arm': 9,
 'aunt': 10,
 'awake': 11,
 'backyard': 12,
 'bad': 13,
 'balloon': 14,
 'bath': 15,
 'because': 16,
 'bed': 17,
 'bedroom': 18,
```

```
'bee': 19,
'before': 20,
'beside': 21,
'better': 22,
'bird': 23,
'black': 24,
'blow': 25,
'blue': 26,
'boat': 27,
'book': 28,
'boy': 29,
'brother': 30,
'brown': 31,
'bug': 32,
'bye': 33,
'callonphone': 34,
'can': 35,
'car': 36,
'carrot': 37,
'cat': 38,
'cereal': 39,
'chair': 40,
'cheek': 41,
'child': 42,
'chin': 43,
'chocolate': 44,
'clean': 45,
'close': 46,
'closet': 47,
'cloud': 48,
'clown': 49,
'cow': 50,
'cowboy': 51,
'cry': 52,
'cut': 53,
'cute': 54,
'dad': 55,
'dance': 56,
'dirty': 57,
'dog': 58,
'doll': 59,
'donkey': 60,
'down': 61,
'drawer': 62,
'drink': 63,
'drop': 64,
'dry': 65,
```

```
'dryer': 66,
'duck': 67,
'ear': 68,
'elephant': 69,
'empty': 70,
'every': 71,
'eye': 72,
'face': 73,
'fall': 74,
'farm': 75,
'fast': 76,
'feet': 77,
'find': 78,
'fine': 79,
'finger': 80,
'finish': 81,
'fireman': 82,
'first': 83,
'fish': 84,
'flag': 85,
'flower': 86,
'food': 87,
'for': 88,
'frenchfries': 89,
'frog': 90,
'garbage': 91,
'gift': 92,
'giraffe': 93,
'girl': 94,
'give': 95,
'glasswindow': 96,
'go': 97,
'goose': 98,
'grandma': 99,
'grandpa': 100,
'grass': 101,
'green': 102,
'gum': 103,
'hair': 104,
'happy': 105,
'hat': 106,
'hate': 107,
'have': 108,
'haveto': 109,
'head': 110,
'hear': 111,
'helicopter': 112,
```

```
'hello': 113,
'hen': 114,
'hesheit': 115,
'hide': 116,
'high': 117,
'home': 118,
'horse': 119,
'hot': 120,
'hungry': 121,
'icecream': 122,
'if': 123,
'into': 124,
'jacket': 125,
'jeans': 126,
'jump': 127,
'kiss': 128,
'kitty': 129,
'lamp': 130,
'later': 131,
'like': 132,
'lion': 133,
'lips': 134,
'listen': 135,
'look': 136,
'loud': 137,
'mad': 138,
'make': 139,
'man': 140,
'many': 141,
'milk': 142,
'minemy': 143,
'mitten': 144,
'mom': 145,
'moon': 146,
'morning': 147,
'mouse': 148,
'mouth': 149,
'nap': 150,
'napkin': 151,
'night': 152,
'no': 153,
'noisy': 154,
'nose': 155,
'not': 156,
'now': 157,
'nuts': 158,
'old': 159,
```

```
'on': 160,
'open': 161,
'orange': 162,
'outside': 163,
'owie': 164,
'owl': 165,
'pajamas': 166,
'pen': 167,
'pencil': 168,
'penny': 169,
'person': 170,
'pig': 171,
'pizza': 172,
'please': 173,
'police': 174,
'pool': 175,
'potty': 176,
'pretend': 177,
'pretty': 178,
'puppy': 179,
'puzzle': 180,
'quiet': 181,
'radio': 182,
'rain': 183,
'read': 184,
'red': 185,
'refrigerator': 186,
'ride': 187,
'room': 188,
'sad': 189,
'same': 190,
'say': 191,
'scissors': 192,
'see': 193,
'shhh': 194,
'shirt': 195,
'shoe': 196,
'shower': 197,
'sick': 198,
'sleep': 199,
'sleepy': 200,
'smile': 201,
'snack': 202,
'snow': 203,
'stairs': 204,
'stay': 205,
'sticky': 206,
```

```
 'store': 207,
 'story': 208,
 'stuck': 209,
 'sun': 210,
 'table': 211,
 'talk': 212,
 'taste': 213,
 'thankyou': 214,
 'that': 215,
 'there': 216,
 'think': 217,
 'thirsty': 218,
 'tiger': 219,
 'time': 220,
 'tomorrow': 221,
 'tongue': 222,
 'tooth': 223,
 'toothbrush': 224,
 'touch': 225,
 'toy': 226,
 'tree': 227,
 'uncle': 228,
 'underwear': 229,
 'up': 230,
 'vacuum': 231,
 'wait': 232,
 'wake': 233,
 'water': 234,
 'wet': 235,
 'weus': 236,
 'where': 237,
 'white': 238,
 'who': 239,
 'why': 240,
 'will': 241,
 'wolf': 242,
 'yellow': 243,
 'yes': 244,
 'yesterday': 245,
 'yourself': 246,
 'yucky': 247,
 'zebra': 248,
 'zipper': 249}
```

[ ]:
```
inverted_mapping = {v: k for k, v in sign_to_index.items()}
```

[ ]:
```
# Convert mapping to list
class_names = [inverted_mapping[i] for i in sorted(inverted_mapping)]
```

[ ]:
```
from sklearn.metrics import classification_report

print(classification_report(y_val, y_val_pred, target_names=class_names))
```

```
              precision    recall  f1-score   support

          TV       0.76      0.95      0.84        60
       after       0.39      0.37      0.38        59
    airplane       0.98      1.00      0.99        57
         all       0.78      0.64      0.70        59
   alligator       0.56      0.77      0.65        61
      animal       0.63      0.54      0.58        48
     another       0.61      0.69      0.65        51
         any       0.56      0.76      0.65        58
       apple       0.94      0.89      0.91        53
         arm       0.78      0.39      0.52        54
        aunt       0.72      0.65      0.69        55
       awake       0.44      0.26      0.33        57
    backyard       0.76      0.59      0.67        59
         bad       0.80      0.67      0.73        60
     balloon       0.70      0.79      0.75        63
        bath       0.65      0.96      0.78        54
     because       0.88      0.83      0.85        59
         bed       0.62      0.96      0.76        55
     bedroom       0.71      0.61      0.65        61
         bee       0.76      0.63      0.69        60
      before       0.73      0.61      0.67        54
      beside       0.64      0.49      0.55        47
      better       0.90      0.77      0.83        57
        bird       0.73      0.97      0.83        58
       black       0.93      0.88      0.90        58
        blow       0.75      0.88      0.81        59
        blue       0.83      0.71      0.76        55
        boat       0.68      0.81      0.74        53
        book       0.71      0.88      0.78        56
         boy       0.92      0.91      0.92        54
     brother       0.84      0.88      0.86        60
       brown       0.84      0.98      0.90        58
         bug       0.67      0.90      0.77        62
         bye       0.66      0.75      0.70        60
 callonphone       1.00      0.72      0.84        57
         can       0.52      0.57      0.54        54
         car       0.79      0.63      0.70        54
      carrot       0.96      0.45      0.62        55
         cat       0.54      0.66      0.59        67
```

cereal	0.79	0.54	0.64	56
chair	0.68	0.85	0.75	52
cheek	0.90	0.74	0.81	61
child	0.76	0.54	0.63	52
chin	0.75	0.78	0.76	58
chocolate	0.83	0.91	0.87	58
clean	0.43	0.87	0.57	53
close	0.76	0.38	0.51	65
closet	0.88	0.57	0.69	61
cloud	0.74	0.75	0.75	61
clown	0.87	0.87	0.87	61
cow	0.92	0.95	0.93	60
cowboy	0.84	0.83	0.83	58
cry	0.87	0.84	0.86	57
cut	0.60	0.79	0.68	57
cute	0.95	0.92	0.93	59
dad	0.81	0.98	0.89	57
dance	0.84	0.70	0.76	46
dirty	0.95	0.75	0.84	53
dog	0.71	0.57	0.63	56
doll	0.98	0.90	0.94	61
donkey	0.88	0.97	0.92	59
down	0.74	0.81	0.78	43
drawer	0.66	0.67	0.67	58
drink	0.90	0.98	0.94	57
drop	0.78	0.43	0.55	49
dry	0.79	0.71	0.75	59
dryer	0.84	0.77	0.80	60
duck	0.64	0.84	0.73	57
ear	0.97	0.48	0.64	60
elephant	0.68	0.58	0.62	59
empty	0.69	0.62	0.65	58
every	0.47	0.48	0.48	50
eye	0.82	0.78	0.80	54
face	0.54	0.72	0.61	53
fall	0.86	0.62	0.72	58
farm	0.87	0.67	0.76	58
fast	0.45	0.27	0.34	51
feet	0.88	0.63	0.74	60
find	0.31	0.56	0.40	59
fine	0.52	0.89	0.66	53
finger	0.72	0.57	0.64	60
finish	0.69	0.78	0.73	60
fireman	0.96	0.83	0.89	60
first	0.85	0.78	0.82	60
fish	0.59	0.71	0.65	56
flag	0.75	0.97	0.84	58
flower	0.93	0.88	0.90	57

food	0.90	0.96	0.93	57
for	0.96	0.95	0.96	57
frenchfries	0.56	0.98	0.71	60
frog	0.98	0.91	0.94	54
garbage	0.97	0.58	0.72	50
gift	0.58	0.84	0.69	58
giraffe	0.91	0.59	0.72	54
girl	0.55	0.42	0.48	52
give	0.59	0.25	0.35	53
glasswindow	0.50	0.35	0.41	54
go	0.86	0.23	0.36	53
goose	0.60	0.05	0.09	62
grandma	0.58	0.75	0.66	57
grandpa	0.98	0.83	0.90	60
grass	0.46	0.47	0.46	60
green	0.79	0.91	0.85	55
gum	0.89	0.93	0.91	59
hair	0.83	0.60	0.70	58
happy	0.82	0.90	0.86	60
hat	0.80	0.81	0.80	43
hate	0.49	0.67	0.57	58
have	0.68	0.88	0.77	49
haveto	0.66	0.85	0.75	55
head	0.79	0.91	0.85	58
hear	0.57	0.56	0.56	68
helicopter	0.66	0.47	0.55	57
hello	0.62	0.79	0.69	57
hen	0.52	0.79	0.63	61
hesheit	0.63	0.77	0.69	60
hide	0.48	0.57	0.52	51
high	0.88	0.93	0.90	54
home	0.98	0.81	0.89	59
horse	0.90	1.00	0.94	60
hot	0.76	0.85	0.80	60
hungry	0.87	0.81	0.84	59
icecream	0.91	0.72	0.80	60
if	0.84	0.93	0.88	55
into	0.67	0.69	0.68	54
jacket	0.70	0.72	0.71	58
jeans	0.76	0.55	0.64	56
jump	0.79	0.63	0.70	59
kiss	0.71	0.63	0.67	59
kitty	0.34	0.26	0.30	65
lamp	0.71	0.59	0.64	61
later	0.59	0.78	0.67	58
like	0.66	0.92	0.77	64
lion	0.90	0.84	0.87	55
lips	0.47	0.58	0.52	60

listen	0.76	0.56	0.65	57
look	0.77	0.44	0.56	62
loud	0.77	0.49	0.60	61
mad	0.63	0.83	0.72	58
make	0.60	0.83	0.70	59
man	0.81	0.78	0.79	59
many	0.40	0.64	0.49	50
milk	0.70	0.78	0.74	58
minemy	0.70	0.97	0.81	60
mitten	0.94	0.48	0.64	62
mom	0.58	0.91	0.71	58
moon	0.93	0.95	0.94	59
morning	0.85	0.93	0.89	55
mouse	0.95	0.92	0.93	60
mouth	0.52	0.22	0.31	60
nap	0.59	0.15	0.24	65
napkin	0.73	0.45	0.56	60
night	0.79	0.58	0.67	45
no	0.68	0.85	0.76	61
noisy	0.92	0.41	0.57	56
nose	0.89	0.88	0.89	58
not	0.59	0.90	0.71	61
now	0.69	0.94	0.80	52
nuts	0.60	0.76	0.67	63
old	0.89	0.63	0.74	54
on	0.78	0.73	0.75	59
open	0.66	0.78	0.71	49
orange	0.94	0.79	0.86	58
outside	0.55	0.48	0.51	61
owie	0.63	0.30	0.40	57
owl	0.96	0.95	0.96	57
pajamas	0.87	0.74	0.80	54
pen	0.69	0.34	0.46	64
pencil	0.61	0.58	0.60	60
penny	0.61	0.46	0.53	54
person	0.36	0.40	0.38	35
pig	0.89	0.92	0.91	53
pizza	0.58	0.38	0.46	66
please	0.90	0.78	0.84	60
police	0.98	0.87	0.92	60
pool	0.90	0.48	0.63	56
potty	0.81	0.94	0.87	53
pretend	0.82	0.84	0.83	61
pretty	0.56	0.52	0.54	58
puppy	0.80	0.52	0.63	62
puzzle	0.68	0.78	0.73	50
quiet	0.70	0.66	0.68	61
radio	0.89	0.65	0.75	60

rain	0.87	0.65	0.74	60
read	0.82	0.75	0.78	53
red	0.90	0.74	0.81	58
refrigerator	0.88	0.53	0.66	55
ride	0.90	0.34	0.49	53
room	0.44	0.67	0.53	60
sad	0.77	0.92	0.84	60
same	0.81	0.80	0.80	59
say	0.38	0.64	0.48	55
scissors	0.60	0.73	0.66	60
see	0.62	0.98	0.76	60
shhh	0.84	0.95	0.89	60
shirt	0.88	0.93	0.90	54
shoe	0.92	0.90	0.91	60
shower	0.72	0.62	0.67	55
sick	0.87	0.70	0.77	56
sleep	0.37	0.67	0.48	57
sleepy	0.54	0.71	0.61	63
smile	0.73	0.73	0.73	56
snack	0.81	0.60	0.69	58
snow	0.94	0.84	0.89	58
stairs	0.83	0.63	0.72	60
stay	0.69	0.75	0.72	56
sticky	0.40	0.79	0.53	53
store	0.82	0.93	0.87	55
story	0.94	0.56	0.70	59
stuck	0.90	0.95	0.92	56
sun	0.62	0.50	0.55	58
table	0.71	0.92	0.80	51
talk	0.97	0.50	0.66	58
taste	0.73	0.91	0.81	57
thankyou	0.38	0.90	0.53	52
that	0.58	0.60	0.59	55
there	0.52	0.46	0.49	50
think	0.58	0.76	0.66	55
thirsty	0.93	0.86	0.89	49
tiger	0.89	0.91	0.90	56
time	0.82	0.84	0.83	50
tomorrow	0.87	0.49	0.63	55
tongue	0.49	0.81	0.61	58
tooth	0.51	0.62	0.56	53
toothbrush	0.67	0.67	0.67	57
touch	0.68	0.60	0.64	57
toy	0.98	0.80	0.88	55
tree	0.81	0.84	0.82	56
uncle	0.93	0.87	0.90	60
underwear	0.86	0.62	0.72	61
up	0.55	0.87	0.68	60

vacuum	0.45	0.48	0.47	52
wait	0.51	0.69	0.59	51
wake	0.41	0.64	0.50	58
water	0.81	0.95	0.87	62
wet	0.46	0.45	0.46	66
weus	0.69	0.88	0.78	57
where	0.80	0.93	0.86	56
white	0.88	0.73	0.80	60
who	0.86	0.80	0.83	60
why	0.82	0.71	0.76	59
will	0.87	0.59	0.70	56
wolf	0.71	0.61	0.66	57
yellow	0.80	0.83	0.81	58
yes	0.63	0.74	0.68	62
yesterday	0.78	0.65	0.71	60
yourself	0.88	0.75	0.81	57
yucky	0.44	0.34	0.38	56
zebra	0.73	0.87	0.79	61
zipper	0.75	0.66	0.70	32
accuracy			0.71	14248
macro avg	0.74	0.71	0.71	14248
weighted avg	0.74	0.71	0.71	14248

The overall ASL Transformer designed by Wijkhuizen, M. are shown in APPENDIX 1. After training and valuation, the Model performance is shown in APPENDIX 2. Wijkhuizen, M.'s transformer model has an overall 0.71 F1 score with a weighted precision of 0.74 and a weighted recall of 0.71. It has outperformed any other model types that we tried. Some ASL word predictions perform better than others; for example, airplane, apple, owl etc., have F1 scores higher than 0.90. and other words like kitty, yucky, and suffer under the F1 score lower than 0.40. However, most words' F1 scores are higher than 0.60, so we could use this model for a real-life application with some limitations.

Reference:

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