Data collection

In [1]:
```
!wget -q https://github.com/sayakpaul/Handwriting-Recognizer-in-Keras/releases/download/v1.0.0/IAM_Words.zip
!unzip -qq IAM_Words.zip
!
!mkdir data
!mkdir data/words
!tar -xf IAM_Words/words.tgz -C data/words
!mv IAM_Words/words.txt data
```

Preview how the dataset is organized. Lines prepended by "#" are just metadata information.

Imports

In [2]:
```
from tensorflow.keras.layers import StringLookup
from tensorflow import keras

import matplotlib.pyplot as plt
import tensorflow as tf
import numpy as np
import os

np.random.seed(42)
tf.random.set_seed(42)
```

Dataset splitting

In [3]:
```
base_path = "data"
words_list = []

words = open(f"{base_path}/words.txt", "r").readlines()
for line in words:
    if line[0] == "#":
        continue
    if line.split(" ")[1] != "err":  # We don't need to deal with errored entries.
        words_list.append(line)

len(words_list)

np.random.shuffle(words_list)
```

We will split the dataset into three subsets with a 90:5:5 ratio (train:validation:test).

In [4]:
```
split_idx = int(0.9 * len(words_list))
train_samples = words_list[:split_idx]
test_samples = words_list[split_idx:]

val_split_idx = int(0.5 * len(test_samples))
validation_samples = test_samples[:val_split_idx]
test_samples = test_samples[val_split_idx:]

assert len(words_list) == len(train_samples) + len(validation_samples) + le
n(
    test_samples
)

print(f"Total training samples: {len(train_samples)}")
print(f"Total validation samples: {len(validation_samples)}")
print(f"Total test samples: {len(test_samples)}")
```

```
Total training samples: 86810
Total validation samples: 4823
Total test samples: 4823
```

Data input pipeline

We start building our data input pipeline by first preparing the image paths.

In [5]:
```
base_image_path = os.path.join(base_path, "words")


def get_image_paths_and_labels(samples):
    paths = []
    corrected_samples = []
    for (i, file_line) in enumerate(samples):
        line_split = file_line.strip()
        line_split = line_split.split(" ")

        # Each line split will have this format for the corresponding imag
e:
        # part1/part1-part2/part1-part2-part3.png
        image_name = line_split[0]
        partI = image_name.split("-")[0]
        partII = image_name.split("-")[1]
        img_path = os.path.join(
            base_image_path, partI, partI + "-" + partII, image_name + ".pn
g"
        )
        if os.path.getsize(img_path):
            paths.append(img_path)
            corrected_samples.append(file_line.split("\n")[0])

    return paths, corrected_samples


train_img_paths, train_labels = get_image_paths_and_labels(train_samples)
validation_img_paths, validation_labels = get_image_paths_and_labels(valida
tion_samples)
test_img_paths, test_labels = get_image_paths_and_labels(test_samples)
```

Then we prepare the ground-truth labels.

In [6]:
```
# Find maximum length and the size of the vocabulary in the training data.
train_labels_cleaned = []
characters = set()
max_len = 0

for label in train_labels:
    label = label.split(" ")[-1].strip()
    for char in label:
        characters.add(char)

    max_len = max(max_len, len(label))
    train_labels_cleaned.append(label)

characters = sorted(list(characters))

print("Maximum length: ", max_len)
print("Vocab size: ", len(characters))

# Check some label samples.
train_labels_cleaned[:10]
```

```
Maximum length:  21
Vocab size:  78
```

Out[6]:
```
['sure',
 'he',
 'during',
 'of',
 'booty',
 'gastronomy',
 'boy',
 'The',
 'and',
 'in']
```

Now we clean the validation and the test labels as well.

In [7]:
```
def clean_labels(labels):
    cleaned_labels = []
    for label in labels:
        label = label.split(" ")[-1].strip()
        cleaned_labels.append(label)
    return cleaned_labels


validation_labels_cleaned = clean_labels(validation_labels)
test_labels_cleaned = clean_labels(test_labels)
```

Building the character vocabulary

In [8]:
```
AUTOTUNE = tf.data.AUTOTUNE

# Mapping characters to integers.
char_to_num = StringLookup(vocabulary=list(characters), mask_token=None)

# Mapping integers back to original characters.
num_to_char = StringLookup(
    vocabulary=char_to_num.get_vocabulary(), mask_token=None, invert=True
)
```

Resizing images without distortion

Instead of square images, many OCR models work with rectangular images. This will become clearer in a moment when we will visualize a few samples from the dataset. While aspect-unaware resizing square images does not introduce a significant amount of distortion this is not the case for rectangular images. But resizing images to a uniform size is a requirement for mini-batching. So we need to perform our resizing such that the following criteria are met:

- Aspect ratio is preserved.
- Content of the images is not affected.

In [9]:
```
def distortion_free_resize(image, img_size):
    w, h = img_size
    image = tf.image.resize(image, size=(h, w), preserve_aspect_ratio=True)

    # Check tha amount of padding needed to be done.
    pad_height = h - tf.shape(image)[0]
    pad_width = w - tf.shape(image)[1]

    # Only necessary if you want to do same amount of padding on both side
s.
    if pad_height % 2 != 0:
        height = pad_height // 2
        pad_height_top = height + 1
        pad_height_bottom = height
    else:
        pad_height_top = pad_height_bottom = pad_height // 2

    if pad_width % 2 != 0:
        width = pad_width // 2
        pad_width_left = width + 1
        pad_width_right = width
    else:
        pad_width_left = pad_width_right = pad_width // 2

    image = tf.pad(
        image,
        paddings=[
            [pad_height_top, pad_height_bottom],
            [pad_width_left, pad_width_right],
            [0, 0],
        ],
    )

    image = tf.transpose(image, perm=[1, 0, 2])
    image = tf.image.flip_left_right(image)
    return image
```

If we just go with the plain resizing then the images would look like so:

Notice how this resizing would have introduced unnecessary stretching.

Putting the utilities together

In [10]:
```
batch_size = 64
padding_token = 99
image_width = 128
image_height = 32


def preprocess_image(image_path, img_size=(image_width, image_height)):
    image = tf.io.read_file(image_path)
    image = tf.image.decode_png(image, 1)
    image = distortion_free_resize(image, img_size)
    image = tf.cast(image, tf.float32) / 255.0
    return image


def vectorize_label(label):
    label = char_to_num(tf.strings.unicode_split(label, input_encoding="UTF
-8"))
    length = tf.shape(label)[0]
    pad_amount = max_len - length
    label = tf.pad(label, paddings=[[0, pad_amount]], constant_values=paddi
ng_token)
    return label


def process_images_labels(image_path, label):
    image = preprocess_image(image_path)
    label = vectorize_label(label)
    return {"image": image, "label": label}


def prepare_dataset(image_paths, labels):
    dataset = tf.data.Dataset.from_tensor_slices((image_paths, labels)).map
(
        process_images_labels, num_parallel_calls=AUTOTUNE
    )
    return dataset.batch(batch_size).cache().prefetch(AUTOTUNE)
```

Prepare `tf.data.Dataset` objects

In [11]:
```
train_ds = prepare_dataset(train_img_paths, train_labels_cleaned)
validation_ds = prepare_dataset(validation_img_paths, validation_labels_cle
aned)
test_ds = prepare_dataset(test_img_paths, test_labels_cleaned)
```

Visualize a few samples

In [12]:
```
for data in train_ds.take(1):
    images, labels = data["image"], data["label"]

    _, ax = plt.subplots(4, 4, figsize=(15, 8))

    for i in range(16):
        img = images[i]
        img = tf.image.flip_left_right(img)
        img = tf.transpose(img, perm=[1, 0, 2])
        img = (img * 255.0).numpy().clip(0, 255).astype(np.uint8)
        img = img[:, :, 0]

        # Gather indices where label!= padding_token.
        label = labels[i]
        indices = tf.gather(label, tf.where(tf.math.not_equal(label, paddin
g_token)))
        # Convert to string.
        label = tf.strings.reduce_join(num_to_char(indices))
        label = label.numpy().decode("utf-8")

        ax[i // 4, i % 4].imshow(img, cmap="gray")
        ax[i // 4, i % 4].set_title(label)
        ax[i // 4, i % 4].axis("off")


plt.show()
```

You will notice that the content of original image is kept as faithful as possible and has been padded accordingly.

Model

In [13]:
```
class CTCLayer(keras.layers.Layer):
    def __init__(self, name=None):
        super().__init__(name=name)
        self.loss_fn = keras.backend.ctc_batch_cost

    def call(self, y_true, y_pred):
        batch_len = tf.cast(tf.shape(y_true)[0], dtype="int64")
        input_length = tf.cast(tf.shape(y_pred)[1], dtype="int64")
        label_length = tf.cast(tf.shape(y_true)[1], dtype="int64")

        input_length = input_length * tf.ones(shape=(batch_len, 1), dtype
="int64")
        label_length = label_length * tf.ones(shape=(batch_len, 1), dtype
="int64")
        loss = self.loss_fn(y_true, y_pred, input_length, label_length)
        self.add_loss(loss)

        # At test time, just return the computed predictions.
        return y_pred


def build_model():
    # Inputs to the model
    input_img = keras.Input(shape=(image_width, image_height, 1), name="ima
ge")
    labels = keras.layers.Input(name="label", shape=(None,))

    # First conv block.
    x = keras.layers.Conv2D(
        32,
        (3, 3),
        activation="relu",
        kernel_initializer="he_normal",
        padding="same",
        name="Conv1",
    )(input_img)
    x = keras.layers.MaxPooling2D((2, 2), name="pool1")(x)

    # Second conv block.
    x = keras.layers.Conv2D(
        64,
        (3, 3),
        activation="relu",
        kernel_initializer="he_normal",
        padding="same",
        name="Conv2",
    )(x)
    x = keras.layers.MaxPooling2D((2, 2), name="pool2")(x)

    # We have used two max pool with pool size and strides 2.
    # Hence, downsampled feature maps are 4x smaller. The number of
    # filters in the last layer is 64. Reshape accordingly before
    # passing the output to the RNN part of the model.
    new_shape = ((image_width // 4), (image_height // 4) * 64)
    x = keras.layers.Reshape(target_shape=new_shape, name="reshape")(x)
    x = keras.layers.Dense(64, activation="relu", name="dense1")(x)
```

```
    x = keras.layers.Dropout(0.2)(x)

    # RNNs.
    x = keras.layers.Bidirectional(
        keras.layers.LSTM(128, return_sequences=True, dropout=0.25)
    )(x)
    x = keras.layers.Bidirectional(
        keras.layers.LSTM(64, return_sequences=True, dropout=0.25)
    )(x)

    # +2 is to account for the two special tokens introduced by the CTC los
s.
    # The recommendation comes here: https://git.io/J0eXP.
    x = keras.layers.Dense(
        len(char_to_num.get_vocabulary()) + 2, activation="softmax", name
="dense2"
    )(x)

    # Add CTC layer for calculating CTC loss at each step.
    output = CTCLayer(name="ctc_loss")(labels, x)

    # Define the model.
    model = keras.models.Model(
        inputs=[input_img, labels], outputs=output, name="handwriting_recog
nizer"
    )
    # Optimizer.
    opt = keras.optimizers.Adam()
    # Compile the model and return.
    model.compile(optimizer=opt)
    return model


# Get the model.
model = build_model()
model.summary()
```

```
Model: "handwriting_recognizer"
_________________________________________________________________________________________
 Layer (type)                Output Shape                 Param #   Connected to
=========================================================================================
 image (InputLayer)          [(None, 128, 32, 1)]         0         []

 Conv1 (Conv2D)              (None, 128, 32, 32)          320       ['image[0][0]']

 pool1 (MaxPooling2D)        (None, 64, 16, 32)           0         ['Conv1[0][0]']

 Conv2 (Conv2D)              (None, 64, 16, 64)           18496     ['pool1[0][0]']

 pool2 (MaxPooling2D)        (None, 32, 8, 64)            0         ['Conv2[0][0]']

 reshape (Reshape)           (None, 32, 512)              0         ['pool2[0][0]']

 dense1 (Dense)              (None, 32, 64)               32832     ['reshape[0][0]']

 dropout (Dropout)           (None, 32, 64)               0         ['dense1[0][0]']

 bidirectional (Bidirection  (None, 32, 256)              197632    ['dropout[0][0]']
 al)

 bidirectional_1 (Bidirecti  (None, 32, 128)              164352    ['bidirectional[0][0]']
 onal)

 label (InputLayer)          [(None, None)]               0         []

 dense2 (Dense)              (None, 32, 81)               10449     ['bidirectional_1[0][0]']

 ctc_loss (CTCLayer)         (None, 32, 81)               0         ['label[0][0]',
                                                                     'dense2[0][0]']

=========================================================================================
Total params: 424081 (1.62 MB)
Trainable params: 424081 (1.62 MB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________________________________
```

Evaluation metric

Edit Distance is the most widely used metric for evaluating OCR models. In this section, we will implement it and use it as a callback to monitor our model.

We first segregate the validation images and their labels for convenience.

In [14]:
```
validation_images = []
validation_labels = []

for batch in validation_ds:
    validation_images.append(batch["image"])
    validation_labels.append(batch["label"])
```

Now, we create a callback to monitor the edit distances.

In [15]:
```
def calculate_edit_distance(labels, predictions):
    # Get a single batch and convert its labels to sparse tensors.
    saprse_labels = tf.cast(tf.sparse.from_dense(labels), dtype=tf.int64)

    # Make predictions and convert them to sparse tensors.
    input_len = np.ones(predictions.shape[0]) * predictions.shape[1]
    predictions_decoded = keras.backend.ctc_decode(
        predictions, input_length=input_len, greedy=True
    )[0][0][:, :max_len]
    sparse_predictions = tf.cast(
        tf.sparse.from_dense(predictions_decoded), dtype=tf.int64
    )

    # Compute individual edit distances and average them out.
    edit_distances = tf.edit_distance(
        sparse_predictions, saprse_labels, normalize=False
    )
    return tf.reduce_mean(edit_distances)


class EditDistanceCallback(keras.callbacks.Callback):
    def __init__(self, pred_model):
        super().__init__()
        self.prediction_model = pred_model

    def on_epoch_end(self, epoch, logs=None):
        edit_distances = []

        for i in range(len(validation_images)):
            labels = validation_labels[i]
            predictions = self.prediction_model.predict(validation_images
[i])
            edit_distances.append(calculate_edit_distance(labels, predictio
ns).numpy())

        print(
            f"Mean edit distance for epoch {epoch + 1}: {np.mean(edit_dista
nces):.4f}"
        )
```

Training

Now we are ready to kick off model training.

In [16]:
```
model = build_model()
```

In [17]:
```
epochs = 75  # To get good results this should be at least 50.
prediction_model = keras.models.Model(
    model.get_layer(name="image").input, model.get_layer(name="dense2").out
put
)
edit_distance_callback = EditDistanceCallback(prediction_model)

# Train the model.
history = model.fit(
    train_ds,
    validation_data=validation_ds,
    epochs=epochs,
    callbacks=[edit_distance_callback],
)
model.save("my_model1.keras")
```

```
Streaming output truncated to the last 5000 lines.
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 18ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 12ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 11ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 10ms/step
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2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 10ms/step
1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 12: 17.6479
1357/1357 [==============================] - 84s 62ms/step - loss: 3.0757 -
val_loss: 2.5661
Epoch 13/75
2/2 [==============================] - 0s 12ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 9ms/step
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2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 13ms/step
2/2 [==============================] - 0s 18ms/step
```

```
2/2 [==============================] - 0s 14ms/step
2/2 [==============================] - 0s 9ms/step
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2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 11ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 10ms/step
1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 13: 17.6647
1357/1357 [==============================] - 79s 58ms/step - loss: 2.9408 -
val_loss: 2.5926
Epoch 14/75
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 11ms/step
2/2 [==============================] - 0s 12ms/step
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```

```
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2/2 [==============================] - 0s 11ms/step
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2/2 [==============================] - 0s 7ms/step
2/2 [==============================] - 0s 10ms/step
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2/2 [==============================] - 0s 17ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 9ms/step
2/2 [==============================] - 0s 15ms/step
2/2 [==============================] - 0s 8ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 11ms/step
2/2 [==============================] - 0s 15ms/step
1/1 [==============================] - 0s 44ms/step
Mean edit distance for epoch 14: 17.6187
```

```
1357/1357 [==============================] - 84s 62ms/step - loss: 2.8456 -
val_loss: 2.4543
Epoch 15/75
2/2 [==============================] - 0s 14ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 10ms/step
2/2 [==============================] - 0s 13ms/step
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2/2 [==============================] - 0s 9ms/step
1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 15: 17.5581
1357/1357 [==============================] - 96s 71ms/step - loss: 2.7301 -
val_loss: 2.3339
Epoch 16/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 37ms/step
Mean edit distance for epoch 16: 17.5712
1357/1357 [==============================] - 90s 67ms/step - loss: 2.6536 -
val_loss: 2.3939
Epoch 17/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 22ms/step
Mean edit distance for epoch 17: 17.6053
1357/1357 [==============================] - 86s 63ms/step - loss: 2.5802 -
val_loss: 2.3898
Epoch 18/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 18: 17.5430
1357/1357 [==============================] - 91s 67ms/step - loss: 2.5133 -
val_loss: 2.2407
Epoch 19/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 19: 17.5643
1357/1357 [==============================] - 91s 67ms/step - loss: 2.4416 -
val_loss: 2.3345
Epoch 20/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 33ms/step
Mean edit distance for epoch 20: 17.5185
1357/1357 [==============================] - 90s 67ms/step - loss: 2.4015 -
val_loss: 2.2600
Epoch 21/75
2/2 [==============================] - 0s 9ms/step
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1/1 [==============================] - 0s 22ms/step
Mean edit distance for epoch 21: 17.4682
1357/1357 [==============================] - 86s 63ms/step - loss: 2.3461 -
val_loss: 2.1316
Epoch 22/75
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Mean edit distance for epoch 22: 17.4683
1357/1357 [==============================] - 84s 62ms/step - loss: 2.2914 -
val_loss: 2.1730
Epoch 23/75
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Mean edit distance for epoch 23: 17.4627
1357/1357 [==============================] - 85s 63ms/step - loss: 2.2353 -
val_loss: 2.1220
Epoch 24/75
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Mean edit distance for epoch 24: 17.4473
1357/1357 [==============================] - 85s 63ms/step - loss: 2.1981 -
val_loss: 2.0183
Epoch 25/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 22ms/step
Mean edit distance for epoch 25: 17.4426
1357/1357 [==============================] - 90s 67ms/step - loss: 2.1587 -
val_loss: 2.0483
Epoch 26/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 26: 17.4469
1357/1357 [==============================] - 88s 65ms/step - loss: 2.1296 -
val_loss: 2.0397
Epoch 27/75
2/2 [==============================] - 0s 9ms/step
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2/2 [==============================] - 0s 9ms/step
1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 27: 17.4424
1357/1357 [==============================] - 88s 65ms/step - loss: 2.0940 -
val_loss: 2.0134
Epoch 28/75
2/2 [==============================] - 0s 8ms/step
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1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 28: 17.4062
1357/1357 [==============================] - 91s 67ms/step - loss: 2.0520 -
val_loss: 1.9337
Epoch 29/75
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1/1 [==============================] - 0s 22ms/step
Mean edit distance for epoch 29: 17.4408
1357/1357 [==============================] - 89s 66ms/step - loss: 2.0258 -
val_loss: 2.0168
Epoch 30/75
2/2 [==============================] - 0s 17ms/step
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1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 30: 17.3906
1357/1357 [==============================] - 92s 68ms/step - loss: 1.9977 -
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val_loss: 1.9031
Epoch 31/75
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 31: 17.3803
1357/1357 [==============================] - 99s 73ms/step - loss: 1.9651 -
val_loss: 1.8660
Epoch 32/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 37ms/step
Mean edit distance for epoch 32: 17.3893
1357/1357 [==============================] - 98s 72ms/step - loss: 1.9416 -
val_loss: 1.8743
Epoch 33/75
2/2 [==============================] - 0s 8ms/step
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 33: 17.3784
1357/1357 [==============================] - 92s 68ms/step - loss: 1.9284 -
val_loss: 1.8825
Epoch 34/75
2/2 [==============================] - 0s 15ms/step
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 34: 17.3959
1357/1357 [==============================] - 92s 68ms/step - loss: 1.8873 -
val_loss: 1.8717
Epoch 35/75
2/2 [==============================] - 0s 10ms/step
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2/2 [==============================] - 0s 9ms/step
1/1 [==============================] - 0s 33ms/step
Mean edit distance for epoch 35: 17.4174
1357/1357 [==============================] - 95s 70ms/step - loss: 1.8710 -
val_loss: 1.9479
Epoch 36/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 36: 17.3872
1357/1357 [==============================] - 95s 70ms/step - loss: 1.8491 -
val_loss: 1.8837
Epoch 37/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 37: 17.3790
1357/1357 [==============================] - 96s 71ms/step - loss: 1.8237 -
val_loss: 1.8187
Epoch 38/75
2/2 [==============================] - 0s 10ms/step
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2/2 [==============================] - 0s 10ms/step
1/1 [==============================] - 0s 22ms/step
Mean edit distance for epoch 38: 17.3733
1357/1357 [==============================] - 96s 71ms/step - loss: 1.8193 -
val_loss: 1.8333
Epoch 39/75
2/2 [==============================] - 0s 11ms/step
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2/2 [==============================] - 0s 12ms/step
1/1 [==============================] - 0s 36ms/step
Mean edit distance for epoch 39: 17.3912
1357/1357 [==============================] - 96s 71ms/step - loss: 1.8005 -
val_loss: 1.8164
Epoch 40/75
2/2 [==============================] - 0s 12ms/step
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1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 40: 17.3735
1357/1357 [==============================] - 97s 72ms/step - loss: 1.7743 -
val_loss: 1.8618
Epoch 41/75
2/2 [==============================] - 0s 9ms/step
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1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 41: 17.3512
1357/1357 [==============================] - 96s 71ms/step - loss: 1.7589 -
val_loss: 1.8144
Epoch 42/75
2/2 [==============================] - 0s 9ms/step
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2/2 [==============================] - 0s 9ms/step
1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 42: 17.3514
1357/1357 [==============================] - 95s 70ms/step - loss: 1.7420 -
val_loss: 1.8086
Epoch 43/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 43: 17.3451
1357/1357 [==============================] - 96s 71ms/step - loss: 1.7274 -
val_loss: 1.7702
Epoch 44/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 44: 17.3256
1357/1357 [==============================] - 97s 72ms/step - loss: 1.7132 -
val_loss: 1.7287
Epoch 45/75
2/2 [==============================] - 0s 9ms/step
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 45: 17.3605
1357/1357 [==============================] - 99s 73ms/step - loss: 1.6978 -
val_loss: 1.7751
Epoch 46/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 37ms/step
Mean edit distance for epoch 46: 17.3093
1357/1357 [==============================] - 98s 72ms/step - loss: 1.6802 -
val_loss: 1.7405
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Epoch 47/75
2/2 [==============================] - 0s 15ms/step
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1/1 [==============================] - 0s 28ms/step
Mean edit distance for epoch 47: 17.3458
1357/1357 [==============================] - 100s 74ms/step - loss: 1.6677
- val_loss: 1.7849
Epoch 48/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 48: 17.3402
1357/1357 [==============================] - 100s 73ms/step - loss: 1.6465
- val_loss: 1.7340
Epoch 49/75
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 49: 17.3408
1357/1357 [==============================] - 99s 73ms/step - loss: 1.6422 -
val_loss: 1.7264
Epoch 50/75
2/2 [==============================] - 0s 8ms/step
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2/2 [==============================] - 0s 17ms/step
1/1 [==============================] - 0s 32ms/step
Mean edit distance for epoch 50: 17.3392
1357/1357 [==============================] - 105s 77ms/step - loss: 1.6243
- val_loss: 1.8088
Epoch 51/75
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1/1 [==============================] - 0s 35ms/step
Mean edit distance for epoch 51: 17.3340
1357/1357 [==============================] - 104s 77ms/step - loss: 1.6187
- val_loss: 1.7337
Epoch 52/75
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 52: 17.3429
1357/1357 [==============================] - 103s 76ms/step - loss: 1.5934
- val_loss: 1.7736
Epoch 53/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 53: 17.3255
1357/1357 [==============================] - 103s 76ms/step - loss: 1.5913
- val_loss: 1.7080
Epoch 54/75
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1/1 [==============================] - 0s 35ms/step
Mean edit distance for epoch 54: 17.3168
1357/1357 [==============================] - 105s 78ms/step - loss: 1.5882
- val_loss: 1.6965
Epoch 55/75
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 55: 17.3181
1357/1357 [==============================] - 104s 77ms/step - loss: 1.5690
- val_loss: 1.7156
Epoch 56/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 56: 17.3122
1357/1357 [==============================] - 105s 77ms/step - loss: 1.5587
- val_loss: 1.7016
Epoch 57/75
2/2 [==============================] - 0s 10ms/step
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2/2 [==============================] - 0s 14ms/step
2/2 [==============================] - 0s 15ms/step
2/2 [==============================] - 0s 20ms/step
1/1 [==============================] - 0s 30ms/step
Mean edit distance for epoch 57: 17.3454
1357/1357 [==============================] - 105s 78ms/step - loss: 1.5583
- val_loss: 1.7462
Epoch 58/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 58: 17.3210
1357/1357 [==============================] - 107s 79ms/step - loss: 1.5355
- val_loss: 1.7082
Epoch 59/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 23ms/step
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Mean edit distance for epoch 59: 17.3227
1357/1357 [==============================] - 106s 78ms/step - loss: 1.5249
- val_loss: 1.7181
Epoch 60/75
2/2 [==============================] - 0s 10ms/step
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 60: 17.3237
1357/1357 [==============================] - 105s 77ms/step - loss: 1.5141
- val_loss: 1.6995
Epoch 61/75
2/2 [==============================] - 0s 9ms/step
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 61: 17.3293
1357/1357 [==============================] - 105s 77ms/step - loss: 1.5089
- val_loss: 1.7161
Epoch 62/75
2/2 [==============================] - 0s 12ms/step
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1/1 [==============================] - 0s 23ms/step
Mean edit distance for epoch 62: 17.3399
1357/1357 [==============================] - 106s 78ms/step - loss: 1.5014
- val_loss: 1.7332
Epoch 63/75
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 63: 17.3154
1357/1357 [==============================] - 109s 81ms/step - loss: 1.4954
- val_loss: 1.6625
Epoch 64/75
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Mean edit distance for epoch 64: 17.3235
1357/1357 [==============================] - 111s 81ms/step - loss: 1.4885
- val_loss: 1.7101
Epoch 65/75
2/2 [==============================] - 0s 11ms/step
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 65: 17.3151
1357/1357 [==============================] - 108s 79ms/step - loss: 1.4839
- val_loss: 1.7162
Epoch 66/75
2/2 [==============================] - 0s 24ms/step
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Mean edit distance for epoch 66: 17.3041
1357/1357 [==============================] - 111s 82ms/step - loss: 1.4710
- val_loss: 1.6950
Epoch 67/75
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 67: 17.3045
1357/1357 [==============================] - 112s 83ms/step - loss: 1.4639
- val_loss: 1.6895
Epoch 68/75
2/2 [==============================] - 0s 11ms/step
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2/2 [==============================] - 0s 14ms/step
2/2 [==============================] - 0s 17ms/step
1/1 [==============================] - 0s 42ms/step
Mean edit distance for epoch 68: 17.3138
1357/1357 [==============================] - 111s 82ms/step - loss: 1.4443
- val_loss: 1.6880
Epoch 69/75
2/2 [==============================] - 0s 10ms/step
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Mean edit distance for epoch 69: 17.3094
1357/1357 [==============================] - 109s 80ms/step - loss: 1.4459
- val_loss: 1.6876
Epoch 70/75
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1/1 [==============================] - 0s 30ms/step
Mean edit distance for epoch 70: 17.3041
1357/1357 [==============================] - 109s 80ms/step - loss: 1.4459
- val_loss: 1.6943
Epoch 71/75
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1/1 [==============================] - 0s 40ms/step
Mean edit distance for epoch 71: 17.3107
1357/1357 [==============================] - 109s 80ms/step - loss: 1.4316
- val_loss: 1.6954
Epoch 72/75
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1/1 [==============================] - 0s 35ms/step
Mean edit distance for epoch 72: 17.3028
1357/1357 [==============================] - 110s 81ms/step - loss: 1.4126
- val_loss: 1.7363
Epoch 73/75
2/2 [==============================] - 0s 13ms/step
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1/1 [==============================] - 0s 25ms/step
Mean edit distance for epoch 73: 17.3063
1357/1357 [==============================] - 109s 81ms/step - loss: 1.4196
- val_loss: 1.6756
Epoch 74/75
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1/1 [==============================] - 0s 24ms/step
Mean edit distance for epoch 74: 17.2968
1357/1357 [==============================] - 108s 79ms/step - loss: 1.4260
- val_loss: 1.6688
Epoch 75/75
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1/1 [==============================] - 0s 28ms/step
Mean edit distance for epoch 75: 17.2941
```

```
1357/1357 [==============================] - 108s 79ms/step - loss: 1.4045
- val_loss: 1.6424
```

Inference

In [ ]:
```
model.save("my_model1.keras")
```

In [18]:
```
# A utility function to decode the output of the network.
def decode_batch_predictions(pred):
    input_len = np.ones(pred.shape[0]) * pred.shape[1]
    # Use greedy search. For complex tasks, you can use beam search.
    results = keras.backend.ctc_decode(pred, input_length=input_len, greedy
=True)[0][0][
        :, :max_len
    ]
    # Iterate over the results and get back the text.
    output_text = []
    for res in results:
        res = tf.gather(res, tf.where(tf.math.not_equal(res, -1)))
        res = tf.strings.reduce_join(num_to_char(res)).numpy().decode("utf-
8")
        output_text.append(res)
    return output_text


#  Let's check results on some test samples.
for batch in test_ds.take(1):
    batch_images = batch["image"]
    _, ax = plt.subplots(4, 4, figsize=(15, 8))

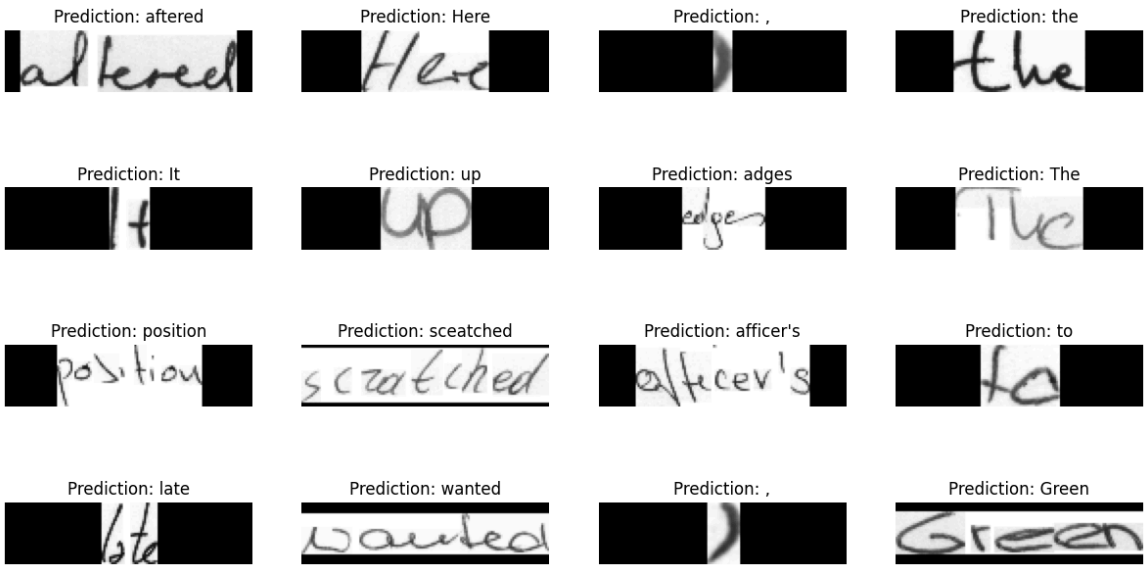
    preds = prediction_model.predict(batch_images)
    pred_texts = decode_batch_predictions(preds)

    for i in range(16):
        img = batch_images[i]
        img = tf.image.flip_left_right(img)
        img = tf.transpose(img, perm=[1, 0, 2])
        img = (img * 255.0).numpy().clip(0, 255).astype(np.uint8)
        img = img[:, :, 0]

        title = f"Prediction: {pred_texts[i]}"
        ax[i // 4, i % 4].imshow(img, cmap="gray")
        ax[i // 4, i % 4].set_title(title)
        ax[i // 4, i % 4].axis("off")

plt.show()
```

```
2/2 [==============================] - 0s 9ms/step
```



In [19]:
```
crt=0
total=0
for batch in validation_ds:
    total+=len(batch)
    batch_images = batch["image"]
    labels = batch['label']
    # _, ax = plt.subplots(4, 4, figsize=(15, 8))

    preds = prediction_model.predict(batch_images)

    pred_texts = decode_batch_predictions(preds)
    labels = tf.strings.reduce_join(num_to_char(labels)).numpy().decode("ut
f-8")
    labels = labels.split("[UNK]")
    labels = [x for x in labels if x!=""]
    for i in range(len(labels)):
      if pred_texts[i]==labels[i]:
        crt+=1
      total+=1
val_acc = crt/total
print(f"Validation accuracy = {val_acc}")
```

```
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2/2 [==============================] - 0s 9ms/step
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1/1 [==============================] - 0s 23ms/step
Validation accuracy = 0.7075376884422111
```

In [20]:
```
crt=0
total=0
for batch in test_ds:
    total+=len(batch)
    batch_images = batch["image"]
    labels = batch['label']
    # _, ax = plt.subplots(4, 4, figsize=(15, 8))

    preds = prediction_model.predict(batch_images)

    pred_texts = decode_batch_predictions(preds)
    labels = tf.strings.reduce_join(num_to_char(labels)).numpy().decode("ut
f-8")
    labels = labels.split("[UNK]")
    labels = [x for x in labels if x!=""]
    for i in range(len(labels)):
      if pred_texts[i]==labels[i]:
        crt+=1
      total+=1
test_acc = crt/total
print(f"Test accuracy = {test_acc}")
```

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1/1 [==============================] - 0s 32ms/step
Test accuracy = 0.7173869346733668
```