

lstm-train-final

November 28, 2025

1 LSTM Model Training for Next-Page Prediction

This notebook trains an LSTM model to predict the next page a user will visit based on their clickstream history.

1.1 Model Architecture

- **Sequence Length:** 20
- **Embedding Size:** 64
- **LSTM Units:** 128
- **Batch Size:** 64
- **Train/Validation Split:** 80/20

1.2 1. Import Libraries

```
[1]: import numpy as np
import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers
import json
import os
from datetime import datetime

print(f"TensorFlow version: {tf.__version__}")
print(f"GPU available: {tf.config.list_physical_devices('GPU')}")
```

```
/Users/katerynababii/Library/Python/3.9/lib/python/site-
packages/urllib3/__init__.py:35: NotOpenSSLWarning: urllib3 v2 only supports
OpenSSL 1.1.1+, currently the 'ssl' module is compiled with 'LibreSSL 2.8.3'.
See: https://github.com/urllib3/urllib3/issues/3020
    warnings.warn(
Matplotlib is building the font cache; this may take a moment.

TensorFlow version: 2.20.0
GPU available: []
```

1.3 2. Load Preprocessed Data

```
[2]: # Configuration
DATA_DIR = './data'
SEQUENCE_LENGTH = 20
EMBEDDING_SIZE = 64
LSTM_UNITS = 128
BATCH_SIZE = 64
EPOCHS = 20
LEARNING_RATE = 0.001

# Load preprocessed data
print("Loading preprocessed data...")
X_train = np.load(f'{DATA_DIR}/X_train.npy')
X_val = np.load(f'{DATA_DIR}/X_val.npy')
y_train = np.load(f'{DATA_DIR}/y_train.npy')
y_val = np.load(f'{DATA_DIR}/y_val.npy')

# Load vocabulary
with open(f'{DATA_DIR}/vocab.json', 'r') as f:
    vocab = json.load(f)

vocab_size = len(vocab)
num_classes = vocab_size - 2 # Exclude <PAD> and <UNK>

print(f"Training samples: {len(X_train)}")
print(f"Validation samples: {len(X_val)}")
print(f"Vocabulary size: {vocab_size}")
print(f"Sequence length: {SEQUENCE_LENGTH}")
```

Loading preprocessed data...
Training samples: 99777
Validation samples: 24945
Vocabulary size: 52
Sequence length: 20

1.4 3. Define Model Architecture

```
[3]: def create_lstm_model(sequence_length, vocab_size, embedding_size, lstm_units, num_classes):
    """
    Create LSTM model for next-page prediction.

    Architecture:
    - Embedding layer: Maps page indices to dense vectors
    - LSTM layer: Processes sequences
    - Dense layer: Output predictions
    """

```

```

model = keras.Sequential([
    # Embedding layer
    layers.Embedding(
        input_dim=vocab_size,
        output_dim=embedding_size,
        input_length=sequence_length,
        name='embedding'
    ),
    # LSTM layer
    layers.LSTM(
        lstm_units,
        return_sequences=False, # Only return final output
        name='lstm'
    ),
    # Dropout for regularization
    layers.Dropout(0.2, name='dropout'),
    # Dense output layer
    layers.Dense(
        num_classes,
        activation='softmax',
        name='output'
    )
])
return model

# Create model
model = create_lstm_model(
    sequence_length=SEQUENCE_LENGTH,
    vocab_size=vocab_size,
    embedding_size=EMBEDDING_SIZE,
    lstm_units=LSTM_UNITS,
    num_classes=num_classes
)

# Compile model
model.compile(
    optimizer=keras.optimizers.Adam(learning_rate=LEARNING_RATE),
    loss='sparse_categorical_crossentropy',
    metrics=['accuracy', 'top_k_categorical_accuracy']
)
# Display model summary
model.summary()

```

```
/Users/katerynababii/Library/Python/3.9/lib/python/site-
packages/keras/src/layers/core/embedding.py:97: UserWarning: Argument
`input_length` is deprecated. Just remove it.
  warnings.warn(
Model: "sequential"
```

Layer (type)	Output Shape	Param #
embedding (Embedding)	?	0 (unbuilt)
lstm (LSTM)	?	0 (unbuilt)
dropout (Dropout)	?	0
output (Dense)	?	0 (unbuilt)

Total params: 0 (0.00 B)

Trainable params: 0 (0.00 B)

Non-trainable params: 0 (0.00 B)

```
[7]: def create_lstm_model(sequence_length, vocab_size, embedding_size, lstm_units, num_classes):
    """
    Create LSTM model for next-page prediction.

    Architecture:
    - Embedding layer: Maps page indices to dense vectors
    - LSTM layer: Processes sequences
    - Dense layer: Output predictions
    """
    model = keras.Sequential([
        # Embedding layer
        layers.Embedding(
            input_dim=vocab_size,
            output_dim=embedding_size,
            input_length=sequence_length,
            name='embedding'
        ),
        # LSTM layer
```

```

        layers.LSTM(
            lstm_units,
            return_sequences=False, # Only return final output
            name='lstm'
        ),

        # Dropout for regularization
        layers.Dropout(0.2, name='dropout'),

        # Dense output layer
        layers.Dense(
            num_classes,
            activation='softmax',
            name='output'
        )
    ])

return model

# Create model
model = create_lstm_model(
    sequence_length=SEQUENCE_LENGTH,
    vocab_size=vocab_size,
    embedding_size=EMBEDDING_SIZE,
    lstm_units=LSTM_UNITS,
    num_classes=num_classes
)

# Compile model
model.compile(
    optimizer=keras.optimizers.Adam(learning_rate=LEARNING_RATE),
    loss='sparse_categorical_crossentropy',
    metrics=['accuracy']
)

# Display model summary
model.summary()

```

Model: "sequential_1"

Layer (type)	Output Shape	Param #
embedding (Embedding)	?	0 (unbuilt)
lstm (LSTM)	?	0 (unbuilt)

```
dropout (Dropout)           ?          0
output (Dense)             ?          0 (unbuilt)
```

Total params: 0 (0.00 B)

Trainable params: 0 (0.00 B)

Non-trainable params: 0 (0.00 B)

1.5 4. Define Callbacks

```
[8]: # Create callbacks
callbacks = [
    # Early stopping
    keras.callbacks.EarlyStopping(
        monitor='val_loss',
        patience=5,
        restore_best_weights=True,
        verbose=1
    ),

    # Model checkpoint
    keras.callbacks.ModelCheckpoint(
        filepath='./models/lstm_model_epoch_{epoch:02d}_val_loss_{val_loss:.4f}.  
h5',
        monitor='val_loss',
        save_best_only=True,
        verbose=1
    ),

    # Reduce learning rate on plateau
    keras.callbacks.ReduceLROnPlateau(
        monitor='val_loss',
        factor=0.5,
        patience=3,
        min_lr=1e-6,
        verbose=1
    ),

    # CSV logger
    keras.callbacks.CSVLogger(
        filename='./results/training_history.csv',
        append=False
```

```

    )
]

# Create directories
os.makedirs('./models', exist_ok=True)
os.makedirs('./results', exist_ok=True)

print("Callbacks configured.")

```

Callbacks configured.

1.6 5. Train Model

```
[9]: print(f"Starting training at {datetime.now()}")
print(f"Epochs: {EPOCHS}")
print(f"Batch size: {BATCH_SIZE}")
print(f"Learning rate: {LEARNING_RATE}")

# Train model
history = model.fit(
    X_train, y_train,
    batch_size=BATCH_SIZE,
    epochs=EPOCHS,
    validation_data=(X_val, y_val),
    callbacks=callbacks,
    verbose=1
)

print(f"Training completed at {datetime.now()}")
```

```
Starting training at 2025-11-28 07:37:43.534686
Epochs: 20
Batch size: 64
Learning rate: 0.001
Epoch 1/20
1547/1560          0s 2ms/step -
accuracy: 0.0196 - loss: 3.9127
Epoch 1: val_loss improved from inf to 3.91251, saving model to
./models/lstm_model_epoch_01_val_loss_3.9125.h5

WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or
`keras.saving.save_model(model)`. This file format is considered legacy. We
recommend using instead the native Keras format, e.g.
`model.save('my_model.keras')` or `keras.saving.save_model(model,
'my_model.keras')`.

1560/1560          4s 2ms/step -
accuracy: 0.0196 - loss: 3.9127 - val_accuracy: 0.0193 - val_loss: 3.9125 -
learning_rate: 0.0010
```

```

Epoch 2/20
1543/1560          0s 2ms/step -
accuracy: 0.0232 - loss: 3.9107
Epoch 2: val_loss did not improve from 3.91251
1560/1560          3s 2ms/step -
accuracy: 0.0232 - loss: 3.9107 - val_accuracy: 0.0196 - val_loss: 3.9138 -
learning_rate: 0.0010
Epoch 3/20
1558/1560          0s 2ms/step -
accuracy: 0.0240 - loss: 3.9089
Epoch 3: val_loss did not improve from 3.91251
1560/1560          3s 2ms/step -
accuracy: 0.0240 - loss: 3.9089 - val_accuracy: 0.0192 - val_loss: 3.9158 -
learning_rate: 0.0010
Epoch 4/20
1555/1560          0s 2ms/step -
accuracy: 0.0246 - loss: 3.9062
Epoch 4: val_loss did not improve from 3.91251

Epoch 4: ReduceLROnPlateau reducing learning rate to 0.0005000000237487257.
1560/1560          4s 2ms/step -
accuracy: 0.0246 - loss: 3.9062 - val_accuracy: 0.0199 - val_loss: 3.9182 -
learning_rate: 0.0010
Epoch 5/20
1549/1560          0s 2ms/step -
accuracy: 0.0279 - loss: 3.9013
Epoch 5: val_loss did not improve from 3.91251
1560/1560          4s 3ms/step -
accuracy: 0.0279 - loss: 3.9014 - val_accuracy: 0.0199 - val_loss: 3.9215 -
learning_rate: 5.0000e-04
Epoch 6/20
1548/1560          0s 2ms/step -
accuracy: 0.0282 - loss: 3.8980
Epoch 6: val_loss did not improve from 3.91251
1560/1560          4s 3ms/step -
accuracy: 0.0282 - loss: 3.8980 - val_accuracy: 0.0189 - val_loss: 3.9253 -
learning_rate: 5.0000e-04
Epoch 6: early stopping
Restoring model weights from the end of the best epoch: 1.
Training completed at 2025-11-28 07:38:06.776736

```

1.7 6. Evaluate Model

```
[12]: # Evaluate on validation set
print("Evaluating model on validation set...")
val_loss, val_accuracy = model.evaluate(X_val, y_val, verbose=1)
```

```
print(f"\nValidation Results:")
print(f"  Loss: {val_loss:.4f}")
print(f"  Accuracy: {val_accuracy:.4f}")
```

Evaluating model on validation set...
780/780 1s 824us/step -
accuracy: 0.0189 - loss: 3.9123

Validation Results:
Loss: 3.9125
Accuracy: 0.0193

1.8 7. Save Final Model

```
[14]: # Save final model
model_path = './models/lstm_final_model.h5'
model.save(model_path)
print(f"Model saved to {model_path}")

# Native Keras format (optional, for your own use)
keras_path = './models/lstm_final_model.keras'
model.save(keras_path)
print(f"Model saved to {keras_path}")
```

WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. This file format is considered legacy. We recommend using instead the native Keras format, e.g.
`model.save('my_model.keras')` or `keras.saving.save_model(model, 'my_model.keras')`.

Model saved to ./models/lstm_final_model.h5
Model saved to ./models/lstm_final_model.keras

1.9 8. Plot Training History

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

# Plot training history
fig, axes = plt.subplots(1, 2, figsize=(12, 4))

# Loss
axes[0].plot(history.history['loss'], label='Training Loss')
axes[0].plot(history.history['val_loss'], label='Validation Loss')
axes[0].set_xlabel('Epoch')
axes[0].set_ylabel('Loss')
axes[0].set_title('Model Loss')
axes[0].legend()
axes[0].grid(True)
```

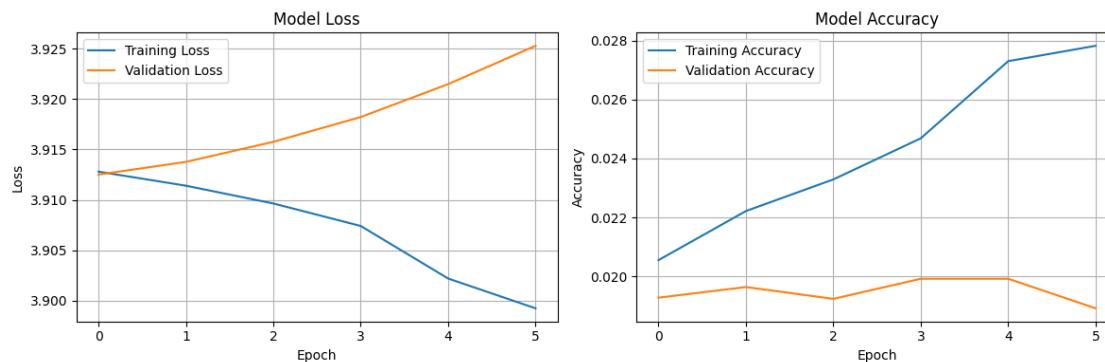
```

# Accuracy
axes[1].plot(history.history['accuracy'], label='Training Accuracy')
axes[1].plot(history.history['val_accuracy'], label='Validation Accuracy')
axes[1].set_xlabel('Epoch')
axes[1].set_ylabel('Accuracy')
axes[1].set_title('Model Accuracy')
axes[1].legend()
axes[1].grid(True)

plt.tight_layout()
plt.savefig('./results/training_history.png', dpi=150)
plt.show()

print("Training history plot saved to ./results/training_history.png")

```



Training history plot saved to ./results/training_history.png

1.10 9. Model Summary and Hyperparameters

```
[16]: # Save model configuration
config = {
    'sequence_length': SEQUENCE_LENGTH,
    'embedding_size': EMBEDDING_SIZE,
    'lstm_units': LSTM_UNITS,
    'batch_size': BATCH_SIZE,
    'learning_rate': LEARNING_RATE,
    'vocab_size': vocab_size,
    'num_classes': num_classes,
    'final_val_loss': float(val_loss),
    'final_val_accuracy': float(val_accuracy),
    'training_samples': int(len(X_train)),
    'validation_samples': int(len(X_val))
}
```

```
with open('./results/model_config.json', 'w') as f:  
    json.dump(config, f, indent=2)  
  
print("Model configuration:")  
for key, value in config.items():  
    print(f"  {key}: {value}")  
  
print("\nConfiguration saved to ./results/model_config.json")
```

```
Model configuration:  
  sequence_length: 20  
  embedding_size: 64  
  lstm_units: 128  
  batch_size: 64  
  learning_rate: 0.001  
  vocab_size: 52  
  num_classes: 50  
  final_val_loss: 3.9125096797943115  
  final_val_accuracy: 0.019282421097159386  
  training_samples: 99777  
  validation_samples: 24945
```

```
Configuration saved to ./results/model_config.json
```