Problem Statement

Traditional chatbots struggle with context-aware question answering where they need to:

- Understand and remember story context
- Process natural language questions
- Provide accurate answers based on stored information

Objective

Build an intelligent chatbot that can:

1. Process story contexts and questions
2. Learn relationships between entities and locations
3. Answer questions accurately based on stored memories
4. Handle simple reasoning tasks (e.g., "Is John in the kitchen?")

Key Challenges Addressed

- Context retention and memory management
- Natural language understanding
- Sequence-to-sequence learning
- Multi-modal input processing (stories + questions)

ENVIRONMENT SETUP & LIBRARY IMPORTS

```
# Install required packages
!pip install keras tensorflow numpy pandas matplotlib

# Import essential libraries
import pickle
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from sklearn.metrics import accuracy_score, classification_report, confusion_matrix
import seaborn as sns

# Keras/TensorFlow imports for deep learning
import tensorflow as tf
from tensorflow.keras.preprocessing.sequence import pad_sequences
from tensorflow.keras.preprocessing.text import Tokenizer
from tensorflow.keras.models import Sequential, Model, load_model
from tensorflow.keras.layers import (Embedding, Input, Activation, Dense,
                                   Permute, Dropout, add, dot, concatenate, LSTM)
from tensorflow.keras.optimizers import RMSprop
from tensorflow.keras.callbacks import EarlyStopping, ModelCheckpoint

print("✅ All libraries imported successfully!")
print(f"TensorFlow version: {tf.__version__}")
```

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Requirement already satisfied: MarkupSafe>=2.1.1 in /usr/local/lib/python3.12/dist-packages (from werkzeug>=1.0.1
✅ All libraries imported successfully!
TensorFlow version: 2.19.0
```

Data Structure Overview

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

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call drive.mount("/content/drive", force
```

```
with open("/content/drive/MyDrive/Chatbot_NLP/Train-Data Set.txt", "rb") as fp:
    Train_data = pickle.load(fp)
```

```
with open("/content/drive/MyDrive/Chatbot_NLP/Test-Data Set.txt", "rb") as fp:
    Test_data = pickle.load(fp)
```

```
print(Test_data[:5])
```

```
[(['Mary', 'got', 'the', 'milk', 'there', '.', 'John', 'moved', 'to', 'the', 'bedroom', '.'], ['Is', 'John', 'in'
```

```
def analyze_data_structure(train_data, test_data):
    """Analyze and display data characteristics"""

    print(f"Training data type: {type(train_data)}")
    print(f"Test data type: {type(test_data)}")
    print(f"Training samples: {len(train_data)}")
    print(f"Test samples: {len(test_data)}")

    # Display sample data point
    if len(train_data) > 0:
        print(f"\n📝 Sample Training Example:")
        print(f"Story: {' '.join(train_data[0][0])}")
        print(f"Question: {' '.join(train_data[0][1])}")
        print(f"Answer: {train_data[0][2]}")

    return train_data, test_data

Train_data, Test_data = analyze_data_structure(Train_data, Test_data)
```

```
Training data type: <class 'list'>
Test data type: <class 'list'>
Training samples: 10000
```

```
Test samples: 1000

📝 Sample Training Example:
Story: Mary moved to the bathroom . Sandra journeyed to the bedroom .
Question: Is Sandra in the hallway ?
Answer: no
```

VOCABULARY BUILDING & TEXT PREPROCESSING

Vocabulary Construction

Building a comprehensive vocabulary from all text data:

1. Extract unique words from stories and questions
2. Add answer tokens ('yes', 'no')
3. Create word-to-index mapping using Keras Tokenizer

Start coding or generate with AI.

```
def build_vocabulary(train_data, test_data):
    """Build vocabulary from all available text data"""

    print("🔤 Building vocabulary...")

    # Initialize vocabulary set
    vocab = set()
    all_data = test_data + train_data

    # Extract vocabulary from stories and questions
    for story, question, answer in all_data:
        vocab = vocab.union(set(story))
        vocab = vocab.union(set(question))

    # Add answer vocabulary
    vocab.add('yes')
    vocab.add('no')

    print(f"📈 Vocabulary Statistics:")
    print(f"Total unique words: {len(vocab)}")
    print(f"Sample words: {list(vocab)[:10]}")

    return vocab, all_data

vocab, all_data = build_vocabulary(Train_data, Test_data)
```

```
🔤 Building vocabulary...
📈 Vocabulary Statistics:
Total unique words: 37
Sample words: ['milk', 'office', 'got', 'put', 'Mary', 'bedroom', '?', 'grabbed', 'to', 'down']
```

Start coding or generate with AI.

```
def analyze_sequence_lengths(all_data):
    """Analyze sequence lengths for padding purposes"""

    story_lengths = [len(data[0]) for data in all_data]
    question_lengths = [len(data[1]) for data in all_data]

    max_story_len = max(story_lengths)
    max_ques_len = max(question_lengths)

    print(f"Sequence Length Analysis:")
    print(f"Max story length: {max_story_len}")
    print(f"Average story length: {np.mean(story_lengths):.2f}")
    print(f"Max question length: {max_ques_len}")
    print(f"Average question length: {np.mean(question_lengths):.2f}")

    plt.figure(figsize=(12, 4))

    plt.subplot(1, 2, 1)
    plt.hist(story_lengths, bins=20, alpha=0.7, color='skyblue')
    plt.title('Distribution of Story Lengths')
    plt.xlabel('Length')
```

```
    plt.ylabel('Frequency')

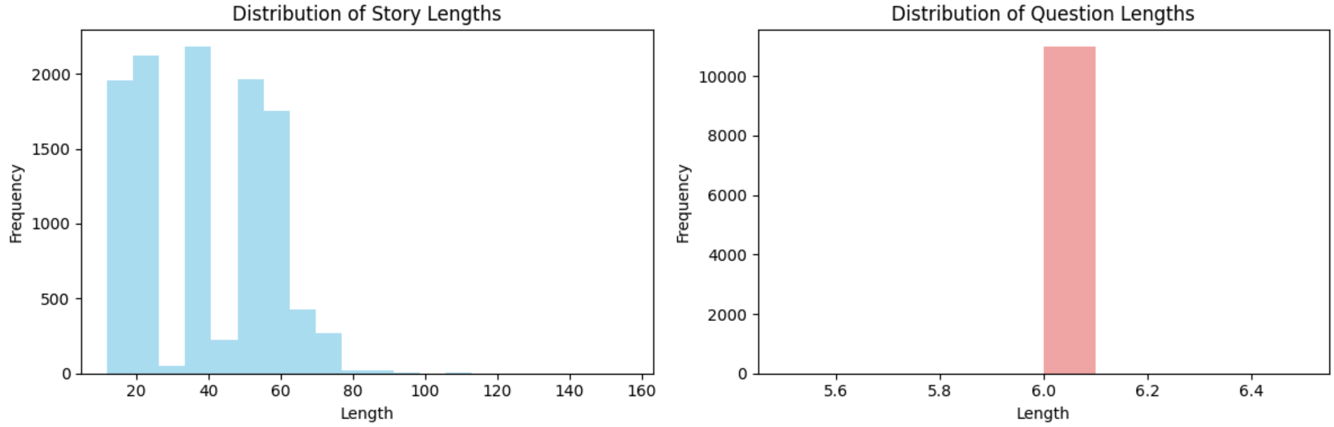
    plt.subplot(1, 2, 2)
    plt.hist(question_lengths, bins=10, alpha=0.7, color='lightcoral')
    plt.title('Distribution of Question Lengths')
    plt.xlabel('Length')
    plt.ylabel('Frequency')

    plt.tight_layout()
    plt.show()

    return max_story_len, max_ques_len

max_story_len, max_ques_len = analyze_sequence_lengths(all_data)
```

```
Sequence Length Analysis:
Max story length: 156
Average story length: 38.50
Max question length: 6
Average question length: 6.00
```



Start coding or generate with AI.

TEXT VECTORIZATION & TOKENIZATION

Text Vectorization Process

Converting text to numerical format:

1. Create tokenizer with no filters to preserve punctuation
2. Fit tokenizer on vocabulary
3. Convert text sequences to integer sequences
4. Pad sequences to uniform length

```
def setup_tokenizer(vocab):
    """Initialize and configure tokenizer"""

    tokenizer = Tokenizer(filters='')  # No filtering to preserve all tokens
    tokenizer.fit_on_texts(vocab)

    vocab_len = len(vocab) + 1  # +1 for padding token

    print(f"🎯 Tokenizer Configuration:")
    print(f"Vocabulary size: {vocab_len}")
    print(f"Sample word indices: {dict(list(tokenizer.word_index.items())[:10])}")

    return tokenizer, vocab_len

tokenizer, vocab_len = setup_tokenizer(vocab)
```

```
🎯 Tokenizer Configuration:
Vocabulary size: 38
Sample word indices: {'milk': 1, 'office': 2, 'got': 3, 'put': 4, 'mary': 5, 'bedroom': 6, '?': 7, 'grabbed': 8,
```

```
tokenizer.word_index
```

```
{'milk': 1,
 'office': 2,
 'got': 3,
 'put': 4,
 'mary': 5,
 'bedroom': 6,
 '?': 7,
 'grabbed': 8,
 'to': 9,
 'down': 10,
 'there': 11,
 'in': 12,
 'dropped': 13,
 'picked': 14,
 'took': 15,
 'kitchen': 16,
 'football': 17,
 'went': 18,
 'the': 19,
 'yes': 20,
 'hallway': 21,
 'is': 22,
 '.': 23,
 'sandra': 24,
 'left': 25,
 'up': 26,
 'back': 27,
 'john': 28,
 'daniel': 29,
 'discarded': 30,
 'moved': 31,
 'garden': 32,
 'journeyed': 33,
 'travelled': 34,
 'no': 35,
 'bathroom': 36,
 'apple': 37}
```

```
def vectorize_stories(data, tokenizer, max_story_len, max_ques_len):
    """Convert text data to numerical vectors"""

    print("🔢 Vectorizing text data...")

    X = []      # Stories
    Xq = []     # Questions
    Y = []      # Answers

    word_index = tokenizer.word_index

    for i, (story, query, answer) in enumerate(data):
        if i < 5: # Print for first 5 examples
            print(f"\nProcessing example {i+1}:")
            print(f"  Original Story: {story}")
            print(f"  Original Question: {query}")
            print(f"  Original Answer: {answer}")


        # Convert words to indices
        x = [word_index[word.lower()] for word in story]
        xq = [word_index[word.lower()] for word in query]

        if i < 5: # Print for first 5 examples
            print(f"  Story indices: {x}")
            print(f"  Question indices: {xq}")

        # One-hot encode answers
        y = np.zeros(len(word_index) + 1)
        y[word_index[answer]] = 1

        if i < 5: # Print for first 5 examples
            print(f"  Answer one-hot: {y}")


        X.append(x)
        Xq.append(xq)
        Y.append(y)

    # Pad sequences to uniform length
    X_padded = pad_sequences(X, maxlen=max_story_len)
    Xq_padded = pad_sequences(Xq, maxlen=max_ques_len)
```

```
    Y_array = np.array(Y)

    print(f"\n✅ Vectorization complete!")
    print(f"Stories shape: {X_padded.shape}")
    print(f"Questions shape: {Xq_padded.shape}")
    print(f"Answers shape: {Y_array.shape}")

    return X_padded, Xq_padded, Y_array


tokenizer, vocab_len = setup_tokenizer(vocab)
inputs_train, queries_train, answers_train = vectorize_stories(Train_data, tokenizer, max_story_len, max_ques_len)
inputs_test, queries_test, answers_test = vectorize_stories(Test_data, tokenizer, max_story_len, max_ques_len)
```

```
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]

✅ Vectorization complete!
Stories shape: (10000, 156)
Questions shape: (10000, 6)
Answers shape: (10000, 38)
🔢 Vectorizing text data...

Processing example 1:
  Original Story: ['Mary', 'got', 'the', 'milk', 'there', '.', 'John', 'moved', 'to', 'the', 'bedroom', '.']
  Original Question: ['Is', 'John', 'in', 'the', 'kitchen', '?']
  Original Answer: no
  Story indices: [5, 3, 19, 1, 11, 23, 28, 31, 9, 19, 6, 23]
  Question indices: [22, 28, 12, 19, 16, 7]
  Answer one-hot: [0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0.]

Processing example 2:
  Original Story: ['Mary', 'got', 'the', 'milk', 'there', '.', 'John', 'moved', 'to', 'the', 'bedroom', '.', 'Ma
  Original Question: ['Is', 'John', 'in', 'the', 'kitchen', '?']
  Original Answer: no
  Story indices: [5, 3, 19, 1, 11, 23, 28, 31, 9, 19, 6, 23, 5, 30, 19, 1, 23, 28, 18, 9, 19, 32, 23]
  Question indices: [22, 28, 12, 19, 16, 7]
  Answer one-hot: [0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0.]

Processing example 3:
  Original Story: ['Mary', 'got', 'the', 'milk', 'there', '.', 'John', 'moved', 'to', 'the', 'bedroom', '.', 'Ma
  Original Question: ['Is', 'John', 'in', 'the', 'garden', '?']
  Original Answer: yes
  Story indices: [5, 3, 19, 1, 11, 23, 28, 31, 9, 19, 6, 23, 5, 30, 19, 1, 23, 28, 18, 9, 19, 32, 23, 29, 31, 9
  Question indices: [22, 28, 12, 19, 32, 7]
  Answer one-hot: [0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0.
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]

Processing example 4:
  Original Story: ['Mary', 'got', 'the', 'milk', 'there', '.', 'John', 'moved', 'to', 'the', 'bedroom', '.', 'Ma
  Original Question: ['Is', 'Daniel', 'in', 'the', 'bathroom', '?']
  Original Answer: yes
  Story indices: [5, 3, 19, 1, 11, 23, 28, 31, 9, 19, 6, 23, 5, 30, 19, 1, 23, 28, 18, 9, 19, 32, 23, 29, 31, 9
  Question indices: [22, 29, 12, 19, 36, 7]
  Answer one-hot: [0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0.
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]

Processing example 5:
  Original Story: ['Mary', 'got', 'the', 'milk', 'there', '.', 'John', 'moved', 'to', 'the', 'bedroom', '.', 'Ma
  Original Question: ['Is', 'Daniel', 'in', 'the', 'bedroom', '?']
  Original Answer: no
  Story indices: [5, 3, 19, 1, 11, 23, 28, 31, 9, 19, 6, 23, 5, 30, 19, 1, 23, 28, 18, 9, 19, 32, 23, 29, 31, 9
  Question indices: [22, 29, 12, 19, 6, 7]
  Answer one-hot: [0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0.]

✅ Vectorization complete!
Stories shape: (1000, 156)
Questions shape: (1000, 6)
Answers shape: (1000, 38)
```

```
print(answers_train.shape)
```

```
(10000, 38)
```

```
print(answers_test.shape)
```

```
(1000, 38)
```

```
inputs_train.shape
```

```
(10000, 156)
```

```
print("First 5 samples of inputs_train:")
print(inputs_train[:5])

print("\nFirst 5 samples of queries_train:")
print(queries_train[:5])

print("\nFirst 5 samples of answers_train:")
print(answers_train[:5])
```

```
First 5 samples of inputs_train:
[[ 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   5 31  9 19 36 23 24 33  9 19  6 23]
 [ 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  5 31  9 19 36 23 24 33  9 19  6 23  5 18
  27  9 19  6 23 29 18 27  9 19 21 23]
 [ 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  5 31  9
  19 36 23 24 33  9 19  6 23  5 18 27  9 19  6 23 29 18 27  9 19 21 23 24
  18  9 19 16 23 29 18 27  9 19 36 23]
 [ 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
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  19  6 23 29 18 27  9 19 21 23 24 18  9 19 16 23 29 18 27  9 19 36 23 29
  14 26 19 17 11 23 29 18  9 19  6 23]
 [ 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  5 31  9 19
  36 23 24 33  9 19  6 23  5 18 27  9 19  6 23 29 18 27  9 19 21 23 24 18
   9 19 16 23 29 18 27  9 19 36 23 29 14 26 19 17 11 23 29 18  9 19  6 23
  28 34  9 19  2 23 24 18  9 19 32 23]]

First 5 samples of queries_train:
[[22 24 12 19 21  7]
 [22 29 12 19 36  7]
 [22 29 12 19  2  7]
 [22 29 12 19  6  7]
 [22 29 12 19  6  7]]

First 5 samples of answers_train:
[[0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0.
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]
 [0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 1. 0. 0. 0.
  0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.]]
```

MODEL ARCHITECTURE & APPROACH

This section details the architecture of the improved Memory Network model designed for context-aware question answering.

Key Components:

1. **Input Encoders**: Process stories with different representations, now with **L2 Regularization** and **Batch Normalization**.
    - Memory encoder (m): For storing contextual information.
    - Context encoder (c): For response generation.

2. **Question Encoder**: Processes question sequences, also with **L2 Regularization** and **Batch Normalization**.
3. **Attention Mechanism**:
   - Computes attention between story and question.
   - Uses dot-product attention with softmax.
4. **Response Generation**:
   - Combines attention weights with context.
   - Uses a stack of **Bidirectional LSTM** and **GRU** layers for enhanced sequential processing and **L2 Regularization**.
   - Dense layer for final classification with **L2 Regularization**.

Architecture Flow:

Story → [Input Encoders (with Reg. & BN)] → Memory Representations Question → [Question Encoder (with Reg. & BN)] → Question Representation [Memory × Question] → Attention Weights [Attention Weights + Context Representation] → Response Response + Question Representation → [Bidirectional LSTM + GRU (with Reg.)] → Processed Representation Processed Representation → [Dense Layer (with Reg.)] → Answer Probability Distribution → [Softmax] → Final Answer

```
# IMPROVED MODEL ARCHITECTURE
from tensorflow.keras.regularizers import l2
from tensorflow.keras.layers import Bidirectional, GRU, BatchNormalization

def build_improved_memory_network(vocab_len, max_story_len, max_ques_len,
                                embedding_dim=128, l2_reg=0.001):
    """Build an improved Memory Network architecture for better accuracy"""

    print("🏗️ Building Improved Memory Network Architecture...")

    # Input layers
    input_sequence = Input((max_story_len,), name='story_input')
    question = Input((max_ques_len,), name='question_input')

    # Enhanced story encoders with regularization
    input_encoder_m = Sequential([
        Embedding(input_dim=vocab_len, output_dim=embedding_dim,
                 input_length=max_story_len,
                 embeddings_regularizer=l2(l2_reg),
                 name='memory_embedding'),
        BatchNormalization(),
        Dropout(0.3, name='memory_dropout')
    ], name='memory_encoder')

    input_encoder_c = Sequential([
        Embedding(input_dim=vocab_len, output_dim=max_ques_len,
                 input_length=max_story_len,
                 embeddings_regularizer=l2(l2_reg),
                 name='context_embedding'),
        BatchNormalization(),
        Dropout(0.3, name='context_dropout')
    ], name='context_encoder')

    # Enhanced question encoder
    question_encoder = Sequential([
        Embedding(input_dim=vocab_len, output_dim=embedding_dim,
                 input_length=max_ques_len,
                 embeddings_regularizer=l2(l2_reg),
                 name='question_embedding'),
        BatchNormalization(),
        Dropout(0.3, name='question_dropout')
    ], name='question_encoder')

    # Encode inputs
    input_encoded_m = input_encoder_m(input_sequence)
    input_encoded_c = input_encoder_c(input_sequence)
    question_encoded = question_encoder(question)

    # Attention mechanism (unchanged - already optimal)
    match = dot([input_encoded_m, question_encoded], axes=(2, 2), name='attention_dot')
    match = Activation('softmax', name='attention_weights')(match)

    # Response generation
    response = add([match, input_encoded_c], name='response_combination')
    response = Permute((2, 1), name='response_permute')(response)
```

```
    # IMPROVED: Bidirectional LSTM + GRU stack
    answer = concatenate([response, question_encoded], name='final_concatenation')
    answer = Bidirectional(LSTM(64, return_sequences=True,
                              kernel_regularizer=l2(l2_reg)))(answer)
    answer = GRU(32, kernel_regularizer=l2(l2_reg))(answer)
    answer = Dropout(0.5, name='final_dropout')(answer)
    answer = Dense(vocab_len, kernel_regularizer=l2(l2_reg), name='output_dense')(answer)
    answer = Activation('softmax', name='final_activation')(answer)

    model = Model([input_sequence, question], answer, name='improved_memory_network')
    return model

# IMPROVED COMPILATION WITH ADAM OPTIMIZER
def compile_improved_model(model, learning_rate=0.001):
    """Compile improved model with Adam optimizer"""

    # Adam optimizer generally performs better than RMSprop
    optimizer = tf.keras.optimizers.Adam(learning_rate=learning_rate)

    model.compile(
        optimizer=optimizer,
        loss='categorical_crossentropy',
        metrics=['accuracy', 'top_k_categorical_accuracy']  # Added top-k accuracy
    )

    print("✅ Improved model compiled successfully!")
    return model

# Build and compile the improved model
improved_model = build_improved_memory_network(vocab_len, max_story_len, max_ques_len)
improved_model = compile_improved_model(improved_model)

# Display the model summary
improved_model.summary()
```

```
🏗 Building Improved Memory Network Architecture...
/usr/local/lib/python3.12/dist-packages/keras/src/layers/core/embedding.py:97: UserWarning: Argument `input_lengt
  warnings.warn(
✅ Improved model compiled successfully!
```

Model: "improved_memory_network"

Layer (type)	Output Shape	Param #	Connected to
story_input (InputLayer)	(None, 156)	0	-
question_input (InputLayer)	(None, 6)	0	-
memory_encoder (Sequential)	(None, 156, 128)	5,376	story_input[0][0]
question_encoder (Sequential)	(None, 6, 128)	5,376	question_input[0…
attention_dot (Dot)	(None, 156, 6)	0	memory_encoder[0… question_encoder…
attention_weights (Activation)	(None, 156, 6)	0	attention_dot[0]…
context_encoder (Sequential)	(None, 156, 6)	252	story_input[0][0]
response_combinati… (Add)	(None, 156, 6)	0	attention_weight… context_encoder[…
response_permute (Permute)	(None, 6, 156)	0	response_combina…
final_concatenation (Concatenate)	(None, 6, 284)	0	response_permute… question_encoder…
bidirectional (Bidirectional)	(None, 6, 128)	178,688	final_concatenat…
gru (GRU)	(None, 32)	15,552	bidirectional[0]…
final_dropout (Dropout)	(None, 32)	0	gru[0][0]
output_dense (Dense)	(None, 38)	1,254	final_dropout[0]…
final_activation (Activation)	(None, 38)	0	output_dense[0][…

Total params: 206,498 (806.63 KB)
Trainable params: 205,974 (804.59 KB)
Non-trainable params: 524 (2.05 KB)

Start coding or generate with AI.

NLP PIPELINE & WORKFLOW OPTIMIZATION

Training Strategy:

1. **Batch Processing**: Efficient memory usage (Increased batch size to 64)
2. **Early Stopping**: Prevent overfitting (Increased patience to 10, added min_delta)
3. **Model Checkpointing**: Save best weights
4. **Learning Rate Scheduling**: Adaptive learning (Exponential decay and ReduceLROnPlateau)
5. **Shuffling**: Important for better training

Monitoring Metrics:

- Training/Validation Loss
- Training/Validation Accuracy
- Top-K Categorical Accuracy (Added metric)
- Convergence Analysis (Visualized with loss plots)

```
# ENHANCED TRAINING WITH LEARNING RATE SCHEDULING
def setup_improved_callbacks(model_name="best_improved_chatbot.h5"):
    """Configure enhanced training callbacks"""
```

```
    callbacks = [
        EarlyStopping(
            monitor='val_accuracy',
            patience=10,  # Increased patience
            restore_best_weights=True,
            verbose=1,
            min_delta=0.001  # Minimum improvement threshold
        ),
        ModelCheckpoint(
            model_name,
            monitor='val_accuracy',
            save_best_only=True,
            verbose=1
        ),
        tf.keras.callbacks.ReduceLROnPlateau(
            monitor='val_loss',
            factor=0.5,
            patience=5,
            min_lr=1e-7,
            verbose=1
        ),
        tf.keras.callbacks.LearningRateScheduler(
            lambda epoch: 0.001 * (0.95 ** epoch)
        )
    ]

    return callbacks

# IMPROVED TRAINING FUNCTION
def train_improved_model(model, inputs_train, queries_train, answers_train,
                         inputs_test, queries_test, answers_test,
                         epochs=50, batch_size=64):  # Increased epochs and batch size
    """Train the improved memory network model"""

    print("🚀 Starting improved model training...")

    callbacks = setup_improved_callbacks()

    history = model.fit(
        [inputs_train, queries_train],
        answers_train,
        batch_size=batch_size,
        epochs=epochs,
        verbose=1,
        validation_data=([inputs_test, queries_test], answers_test),
        callbacks=callbacks,
        shuffle=True  # Important for better training
    )

    print("✅ Improved training completed!")
    return history

# Assume plot_training_history is defined here or imported from a previous cell
def plot_training_history(history):
    """Visualize training progress"""

    fig, axes = plt.subplots(2, 2, figsize=(15, 10))

    # Training & Validation Loss
    axes[0, 0].plot(history.history['loss'], label='Training Loss', color='blue')
    axes[0, 0].plot(history.history['val_loss'], label='Validation Loss', color='red')
    axes[0, 0].set_title('Model Loss Over Time')
    axes[0, 0].set_xlabel('Epochs')
    axes[0, 0].set_ylabel('Loss')
    axes[0, 0].legend()
    axes[0, 0].grid(True, alpha=0.3)

    # Training & Validation Accuracy
    axes[0, 1].plot(history.history['accuracy'], label='Training Accuracy', color='green')
    axes[0, 1].plot(history.history['val_accuracy'], label='Validation Accuracy', color='orange')
    axes[0, 1].set_title('Model Accuracy Over Time')
    axes[0, 1].set_xlabel('Epochs')
    axes[0, 1].set_ylabel('Accuracy')
    axes[0, 1].legend()
    axes[0, 1].grid(True, alpha=0.3)

    # Learning Rate vs Loss
```

```
    axes[1, 0].plot(history.history['loss'], color='purple')
    axes[1, 0].set_title('Training Loss Convergence')
    axes[1, 0].set_xlabel('Epochs')
    axes[1, 0].set_ylabel('Training Loss')
    axes[1, 0].grid(True, alpha=0.3)

    # Performance Metrics Summary
    final_train_acc = history.history['accuracy'][-1]
    final_val_acc = history.history['val_accuracy'][-1]
    final_train_loss = history.history['loss'][-1]
    final_val_loss = history.history['val_loss'][-1]

    metrics_text = f"""
    Final Metrics:

    Training Accuracy: {final_train_acc:.4f}
    Validation Accuracy: {final_val_acc:.4f}

    Training Loss: {final_train_loss:.4f}
    Validation Loss: {final_val_loss:.4f}

    Overfitting Check:
    Acc Diff: {final_train_acc - final_val_acc:.4f}
    Loss Diff: {final_val_loss - final_train_loss:.4f}
    """

    axes[1, 1].text(0.1, 0.5, metrics_text, fontsize=12, verticalalignment='center')
    axes[1, 1].set_title('Training Summary')
    axes[1, 1].axis('off')

    plt.tight_layout()
    plt.show()

history_improved = train_improved_model(improved_model, inputs_train, queries_train, answers_train,
                                        inputs_test, queries_test, answers_test)
plot_training_history(history_improved)
```

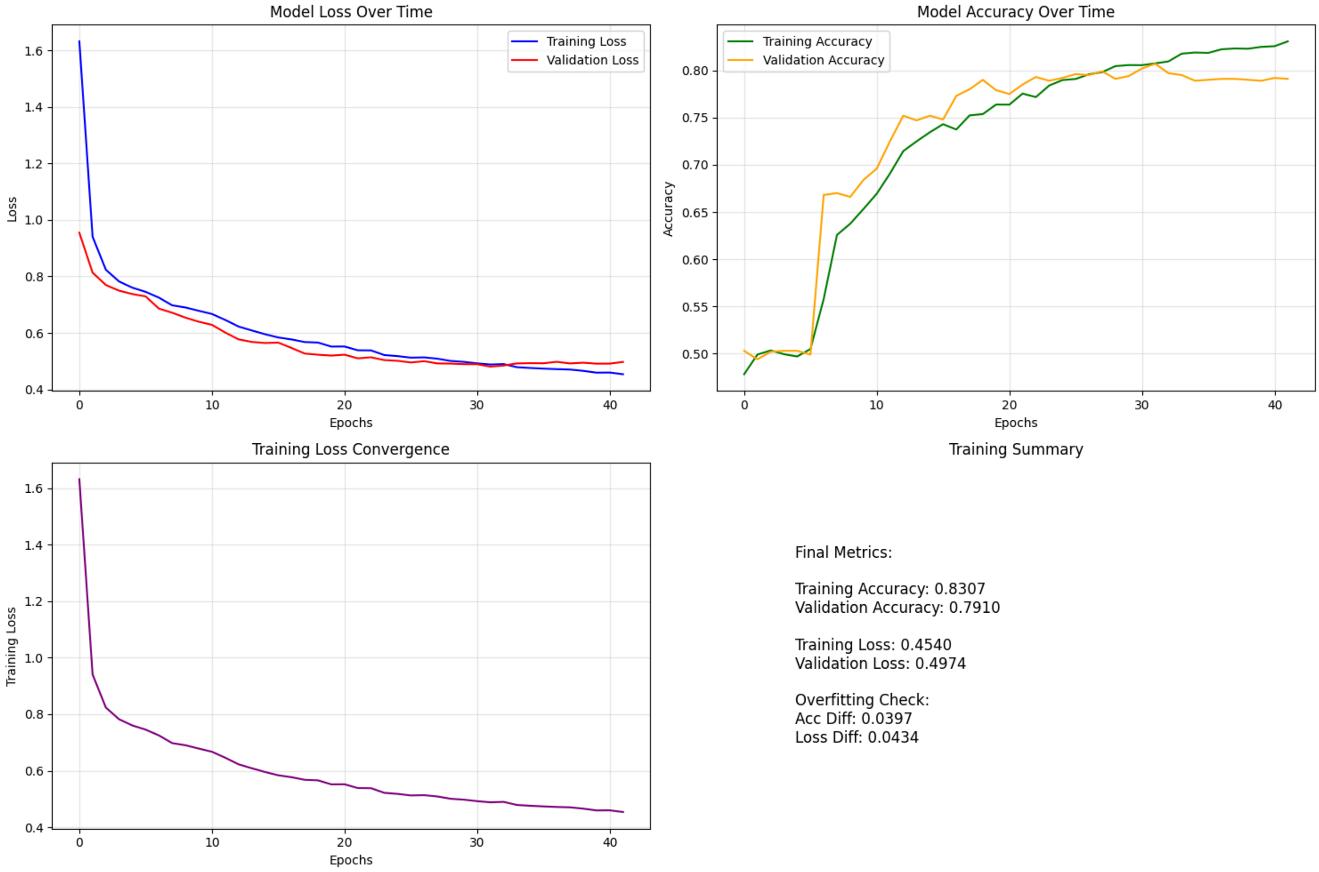
```
🚀 Starting improved model training...
Epoch 1/50
156/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.4365 - loss: 2.3104 - top_k_categorical_accuracy: 0.910
Epoch 1: val_accuracy improved from -inf to 0.50300, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`.
157/157 ━━━━━━━━━━━━━━━━━━━━ 16s 17ms/step - accuracy: 0.4370 - loss: 2.3019 - top_k_categorical_accuracy: 0.91
Epoch 2/50
156/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.5045 - loss: 0.9858 - top_k_categorical_accuracy: 1.000
Epoch 2: val_accuracy did not improve from 0.50300
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 13ms/step - accuracy: 0.5045 - loss: 0.9853 - top_k_categorical_accuracy: 1.000
Epoch 3/50
154/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.5033 - loss: 0.8419 - top_k_categorical_accuracy: 1.000
Epoch 3: val_accuracy did not improve from 0.50300
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 13ms/step - accuracy: 0.5033 - loss: 0.8415 - top_k_categorical_accuracy: 1.000
Epoch 4/50
153/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.4994 - loss: 0.7897 - top_k_categorical_accuracy: 1.000
Epoch 4: val_accuracy did not improve from 0.50300
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 13ms/step - accuracy: 0.4994 - loss: 0.7895 - top_k_categorical_accuracy: 1.000
Epoch 5/50
156/157 ━━━━━━━━━━━━━━━━━━━━ 0s 19ms/step - accuracy: 0.5111 - loss: 0.7607 - top_k_categorical_accuracy: 1.000
Epoch 5: val_accuracy did not improve from 0.50300
157/157 ━━━━━━━━━━━━━━━━━━━━ 4s 21ms/step - accuracy: 0.5109 - loss: 0.7607 - top_k_categorical_accuracy: 1.000
Epoch 6/50
153/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.4986 - loss: 0.7490 - top_k_categorical_accuracy: 1.000
Epoch 6: val_accuracy did not improve from 0.50300
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.4988 - loss: 0.7489 - top_k_categorical_accuracy: 1.000
Epoch 7/50
156/157 ━━━━━━━━━━━━━━━━━━━━ 0s 14ms/step - accuracy: 0.5325 - loss: 0.7331 - top_k_categorical_accuracy: 1.000
Epoch 7: val_accuracy improved from 0.50300 to 0.66800, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`.
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 15ms/step - accuracy: 0.5329 - loss: 0.7330 - top_k_categorical_accuracy: 1.000
Epoch 8/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.6173 - loss: 0.7057 - top_k_categorical_accuracy: 1.000
Epoch 8: val_accuracy improved from 0.66800 to 0.67000, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`.
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.6174 - loss: 0.7056 - top_k_categorical_accuracy: 1.000
Epoch 9/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.6432 - loss: 0.6897 - top_k_categorical_accuracy: 1.000
Epoch 9: val_accuracy did not improve from 0.67000
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 13ms/step - accuracy: 0.6432 - loss: 0.6897 - top_k_categorical_accuracy: 1.000
Epoch 10/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 19ms/step - accuracy: 0.6500 - loss: 0.6787 - top_k_categorical_accuracy: 1.000
Epoch 10: val_accuracy improved from 0.67000 to 0.68400, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`.
157/157 ━━━━━━━━━━━━━━━━━━━━ 4s 20ms/step - accuracy: 0.6501 - loss: 0.6787 - top_k_categorical_accuracy: 1.000
Epoch 11/50
154/157 ━━━━━━━━━━━━━━━━━━━━ 0s 13ms/step - accuracy: 0.6745 - loss: 0.6635 - top_k_categorical_accuracy: 1.000
Epoch 11: val_accuracy improved from 0.68400 to 0.69600, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`.
157/157 ━━━━━━━━━━━━━━━━━━━━ 4s 14ms/step - accuracy: 0.6743 - loss: 0.6636 - top_k_categorical_accuracy: 1.000
Epoch 12/50
153/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.6916 - loss: 0.6504 - top_k_categorical_accuracy: 1.000
Epoch 12: val_accuracy improved from 0.69600 to 0.72500, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`.
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.6916 - loss: 0.6503 - top_k_categorical_accuracy: 1.000
Epoch 13/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 13ms/step - accuracy: 0.7159 - loss: 0.6212 - top_k_categorical_accuracy: 1.000
Epoch 13: val_accuracy improved from 0.72500 to 0.75200, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`.
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.7158 - loss: 0.6212 - top_k_categorical_accuracy: 1.000
Epoch 14/50
156/157 ━━━━━━━━━━━━━━━━━━━━ 0s 17ms/step - accuracy: 0.7273 - loss: 0.6099 - top_k_categorical_accuracy: 1.000
Epoch 14: val_accuracy did not improve from 0.75200
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 18ms/step - accuracy: 0.7273 - loss: 0.6099 - top_k_categorical_accuracy: 1.000
Epoch 15/50
155/157 ━━━━━━━━━━━━━━━━━━━━ 0s 16ms/step - accuracy: 0.7359 - loss: 0.5989 - top_k_categorical_accuracy: 1.000
Epoch 15: val_accuracy did not improve from 0.75200
157/157 ━━━━━━━━━━━━━━━━━━━━ 5s 17ms/step - accuracy: 0.7359 - loss: 0.5988 - top_k_categorical_accuracy: 1.000
Epoch 16/50
153/157 ━━━━━━━━━━━━━━━━━━━━ 0s 14ms/step - accuracy: 0.7446 - loss: 0.5873 - top_k_categorical_accuracy: 1.000
Epoch 16: val_accuracy did not improve from 0.75200
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 15ms/step - accuracy: 0.7446 - loss: 0.5872 - top_k_categorical_accuracy: 1.000
Epoch 17/50
156/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.7332 - loss: 0.5814 - top_k_categorical_accuracy: 1.000
Epoch 17: val_accuracy improved from 0.75200 to 0.77300, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`.
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 13ms/step - accuracy: 0.7333 - loss: 0.5814 - top_k_categorical_accuracy: 1.000
Epoch 18/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 16ms/step - accuracy: 0.7473 - loss: 0.5711 - top_k_categorical_accuracy: 1.000
Epoch 18: val_accuracy improved from 0.77300 to 0.78000, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`.
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 19ms/step - accuracy: 0.7473 - loss: 0.5711 - top_k_categorical_accuracy: 1.000
Epoch 19/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.7556 - loss: 0.5709 - top_k_categorical_accuracy: 1.000
Epoch 19: val_accuracy improved from 0.78000 to 0.79000, saving model to best_improved_chatbot.h5
```

```
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. 
157/157 ━━━━━━━━━━━━━━━━━━━━ 4s 14ms/step - accuracy: 0.7556 - loss: 0.5709 - top_k_categorical_accuracy: 1.000
Epoch 20/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.7609 - loss: 0.5527 - top_k_categorical_accuracy: 1.000
Epoch 20: val_accuracy did not improve from 0.79000
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 13ms/step - accuracy: 0.7609 - loss: 0.5527 - top_k_categorical_accuracy: 1.000
Epoch 21/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.7655 - loss: 0.5467 - top_k_categorical_accuracy: 1.000
Epoch 21: val_accuracy did not improve from 0.79000
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 13ms/step - accuracy: 0.7655 - loss: 0.5467 - top_k_categorical_accuracy: 1.000
Epoch 22/50
156/157 ━━━━━━━━━━━━━━━━━━━━ 0s 15ms/step - accuracy: 0.7794 - loss: 0.5326 - top_k_categorical_accuracy: 1.000
Epoch 22: val_accuracy did not improve from 0.79000
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 17ms/step - accuracy: 0.7794 - loss: 0.5326 - top_k_categorical_accuracy: 1.000
Epoch 23/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 19ms/step - accuracy: 0.7778 - loss: 0.5345 - top_k_categorical_accuracy: 1.000
Epoch 23: val_accuracy improved from 0.79000 to 0.79300, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. 
157/157 ━━━━━━━━━━━━━━━━━━━━ 6s 21ms/step - accuracy: 0.7778 - loss: 0.5345 - top_k_categorical_accuracy: 1.000
Epoch 24/50
153/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.7828 - loss: 0.5296 - top_k_categorical_accuracy: 1.000
Epoch 24: val_accuracy did not improve from 0.79300
157/157 ━━━━━━━━━━━━━━━━━━━━ 4s 13ms/step - accuracy: 0.7829 - loss: 0.5294 - top_k_categorical_accuracy: 1.000
Epoch 25/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 14ms/step - accuracy: 0.7933 - loss: 0.5138 - top_k_categorical_accuracy: 1.000
Epoch 25: val_accuracy did not improve from 0.79300
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 16ms/step - accuracy: 0.7933 - loss: 0.5138 - top_k_categorical_accuracy: 1.000
Epoch 26/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 17ms/step - accuracy: 0.7906 - loss: 0.5174 - top_k_categorical_accuracy: 1.000
Epoch 26: val_accuracy improved from 0.79300 to 0.79600, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. 
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 19ms/step - accuracy: 0.7906 - loss: 0.5174 - top_k_categorical_accuracy: 1.000
Epoch 27/50
155/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.8017 - loss: 0.5038 - top_k_categorical_accuracy: 1.000
Epoch 27: val_accuracy did not improve from 0.79600
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 13ms/step - accuracy: 0.8016 - loss: 0.5040 - top_k_categorical_accuracy: 1.000
Epoch 28/50
154/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.8027 - loss: 0.5043 - top_k_categorical_accuracy: 1.000
Epoch 28: val_accuracy improved from 0.79600 to 0.79900, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. 
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.8025 - loss: 0.5045 - top_k_categorical_accuracy: 1.000
Epoch 29/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.8061 - loss: 0.4929 - top_k_categorical_accuracy: 1.000
Epoch 29: val_accuracy did not improve from 0.79900
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 14ms/step - accuracy: 0.8061 - loss: 0.4930 - top_k_categorical_accuracy: 1.000
Epoch 30/50
154/157 ━━━━━━━━━━━━━━━━━━━━ 0s 13ms/step - accuracy: 0.8109 - loss: 0.4909 - top_k_categorical_accuracy: 1.000
Epoch 30: val_accuracy did not improve from 0.79900
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.8108 - loss: 0.4911 - top_k_categorical_accuracy: 1.000
Epoch 31/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 20ms/step - accuracy: 0.8110 - loss: 0.4886 - top_k_categorical_accuracy: 1.000
Epoch 31: val_accuracy improved from 0.79900 to 0.80200, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. 
157/157 ━━━━━━━━━━━━━━━━━━━━ 4s 22ms/step - accuracy: 0.8110 - loss: 0.4887 - top_k_categorical_accuracy: 1.000
Epoch 32/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 13ms/step - accuracy: 0.8095 - loss: 0.4823 - top_k_categorical_accuracy: 1.000
Epoch 32: val_accuracy improved from 0.80200 to 0.80700, saving model to best_improved_chatbot.h5
WARNING:absl:You are saving your model as an HDF5 file via `model.save()` or `keras.saving.save_model(model)`. 
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.8095 - loss: 0.4823 - top_k_categorical_accuracy: 1.000
Epoch 33/50
153/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.8084 - loss: 0.4907 - top_k_categorical_accuracy: 1.000
Epoch 33: val_accuracy did not improve from 0.80700
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 13ms/step - accuracy: 0.8085 - loss: 0.4907 - top_k_categorical_accuracy: 1.000
Epoch 34/50
153/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.8168 - loss: 0.4743 - top_k_categorical_accuracy: 1.000
Epoch 34: val_accuracy did not improve from 0.80700
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.8168 - loss: 0.4745 - top_k_categorical_accuracy: 1.000
Epoch 35/50
155/157 ━━━━━━━━━━━━━━━━━━━━ 0s 13ms/step - accuracy: 0.8198 - loss: 0.4764 - top_k_categorical_accuracy: 1.000
Epoch 35: val_accuracy did not improve from 0.80700
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.8198 - loss: 0.4764 - top_k_categorical_accuracy: 1.000
Epoch 36/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 17ms/step - accuracy: 0.8200 - loss: 0.4679 - top_k_categorical_accuracy: 1.000
Epoch 36: val_accuracy did not improve from 0.80700
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 20ms/step - accuracy: 0.8200 - loss: 0.4679 - top_k_categorical_accuracy: 1.000
Epoch 37/50
154/157 ━━━━━━━━━━━━━━━━━━━━ 0s 15ms/step - accuracy: 0.8161 - loss: 0.4749 - top_k_categorical_accuracy: 1.000
Epoch 37: val_accuracy did not improve from 0.80700

Epoch 37: ReduceLROnPlateau reducing learning rate to 7.888960681157187e-05.
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 16ms/step - accuracy: 0.8163 - loss: 0.4748 - top_k_categorical_accuracy: 1.000
Epoch 38/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 12ms/step - accuracy: 0.8141 - loss: 0.4844 - top_k_categorical_accuracy: 1.000
Epoch 38: val_accuracy did not improve from 0.80700
157/157 ━━━━━━━━━━━━━━━━━━━━ 2s 14ms/step - accuracy: 0.8141 - loss: 0.4843 - top_k_categorical_accuracy: 1.000
Epoch 39/50
```

```
Epoch 39/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 13ms/step - accuracy: 0.8168 - loss: 0.4731 - top_k_categorical_accuracy: 1.000
Epoch 39: val_accuracy did not improve from 0.80700
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 14ms/step - accuracy: 0.8169 - loss: 0.4730 - top_k_categorical_accuracy: 1.000
Epoch 40/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 13ms/step - accuracy: 0.8266 - loss: 0.4542 - top_k_categorical_accuracy: 1.000
Epoch 40: val_accuracy did not improve from 0.80700
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 14ms/step - accuracy: 0.8266 - loss: 0.4542 - top_k_categorical_accuracy: 1.000
Epoch 41/50
157/157 ━━━━━━━━━━━━━━━━━━━━ 0s 17ms/step - accuracy: 0.8237 - loss: 0.4583 - top_k_categorical_accuracy: 1.000
Epoch 41: val_accuracy did not improve from 0.80700
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 19ms/step - accuracy: 0.8237 - loss: 0.4583 - top_k_categorical_accuracy: 1.000
Epoch 42/50
155/157 ━━━━━━━━━━━━━━━━━━━━ 0s 16ms/step - accuracy: 0.8300 - loss: 0.4476 - top_k_categorical_accuracy: 1.000
Epoch 42: val_accuracy did not improve from 0.80700

Epoch 42: ReduceLROnPlateau reducing learning rate to 6.104327621869743e-05.
157/157 ━━━━━━━━━━━━━━━━━━━━ 3s 16ms/step - accuracy: 0.8300 - loss: 0.4478 - top_k_categorical_accuracy: 1.000
Epoch 42: early stopping
Restoring model weights from the end of the best epoch: 32.
✅ Improved training completed!
```



Model Evaluation & Performance Metrics

Evaluation Components:

Prediction Accuracy: Overall correctness Confidence Analysis: Prediction certainty Error Analysis: Understanding failure cases Sample Predictions: Qualitative assessment

```
def evaluate_model_performance(model, inputs_test, queries_test, answers_test,
                             test_data, tokenizer):
    """Comprehensive model evaluation"""

    print("📊 Evaluating model performance...")

    # Get predictions
    pred_results = model.predict([inputs_test, queries_test])

    # Calculate accuracy
    predicted_classes = np.argmax(pred_results, axis=1)
    true_classes = np.argmax(answers_test, axis=1)
    accuracy = accuracy_score(true_classes, predicted_classes)

    print(f"🎯 Model Performance:")
    print(f"Overall Accuracy: {accuracy:.4f}")

    # Detailed classification report
    print("\n📈 Detailed Classification Report:")

    # Get class names
    class_names = []
    for idx in [tokenizer.word_index['yes'], tokenizer.word_index['no']]:
        for word, word_idx in tokenizer.word_index.items():
            if word_idx == idx:
                class_names.append(word)

    print(classification_report(true_classes, predicted_classes,
                              target_names=class_names))

    # Confusion Matrix
    plt.figure(figsize=(8, 6))
    cm = confusion_matrix(true_classes, predicted_classes)
    sns.heatmap(cm, annot=True, fmt='d', cmap='Blues',
                xticklabels=class_names, yticklabels=class_names)
    plt.title('Confusion Matrix')
    plt.ylabel('True Label')
    plt.xlabel('Predicted Label')
    plt.show()

    return pred_results, accuracy

def analyze_confidence_distribution(pred_results):
    """Analyze prediction confidence"""

    # Get maximum probabilities (confidence scores)
    confidence_scores = np.max(pred_results, axis=1)

    plt.figure(figsize=(12, 4))

    plt.subplot(1, 2, 1)
    plt.hist(confidence_scores, bins=20, alpha=0.7, color='lightgreen')
    plt.title('Distribution of Prediction Confidence')
    plt.xlabel('Confidence Score')
    plt.ylabel('Frequency')
    plt.axvline(np.mean(confidence_scores), color='red', linestyle='--',
                label=f'Mean: {np.mean(confidence_scores):.3f}')
    plt.legend()

    plt.subplot(1, 2, 2)
    plt.boxplot(confidence_scores)
    plt.title('Confidence Score Statistics')
    plt.ylabel('Confidence Score')

    plt.tight_layout()
    plt.show()

    print(f"📊 Confidence Statistics:")
```

```
    print(f"Mean Confidence: {np.mean(confidence_scores):.4f}")
    print(f"Std Confidence: {np.std(confidence_scores):.4f}")
    print(f"Min Confidence: {np.min(confidence_scores):.4f}")
    print(f"Max Confidence: {np.max(confidence_scores):.4f}")

def show_sample_predictions(model, test_data, inputs_test, queries_test,
                           tokenizer, num_samples=5):
    """Display sample predictions with context"""

    print("🔍 Sample Predictions Analysis:")
    print("=" * 60)

    pred_results = model.predict([inputs_test, queries_test])

    for i in range(min(num_samples, len(test_data))):
        # Get story and question
        story = ' '.join(test_data[i][0])
        question = ' '.join(test_data[i][1])
        true_answer = test_data[i][2] # Accessing the answer from the tuple

        # Get predicted answer
        pred_idx = np.argmax(pred_results[i])
        confidence = pred_results[i][pred_idx]

        pred_answer = None
        for word, idx in tokenizer.word_index.items():
            if idx == pred_idx:
                pred_answer = word
                break

        # Display results
        print(f"\n📖 Example {i + 1}:")
        print(f"Story: {story}")
        print(f"Question: {question}")
        print(f"True Answer: {true_answer}")
        print(f"Predicted Answer: {pred_answer}")
        print(f"Confidence: {confidence:.4f}")

        # Status indicator
        status = "✅ CORRECT" if pred_answer == true_answer else "❌ INCORRECT"
        print(f"Status: {status}")
        print("-" * 60)

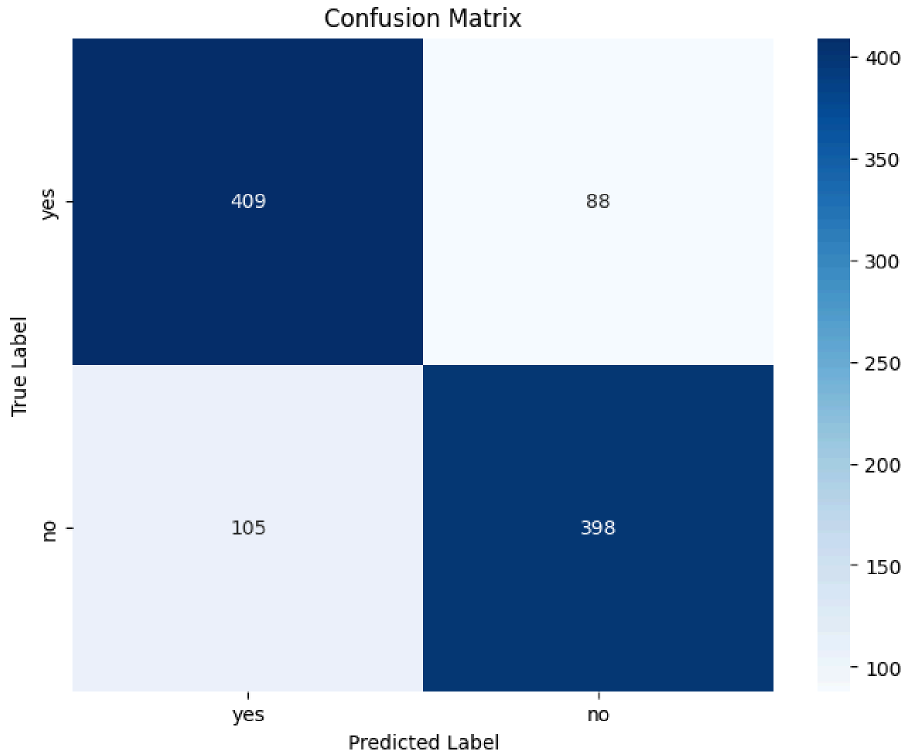
pred_results, accuracy = evaluate_model_performance(improved_model, inputs_test, queries_test,answers_test, Test_data,
analyze_confidence_distribution(pred_results)
show_sample_predictions(improved_model, Test_data, inputs_test, queries_test, tokenizer)
```

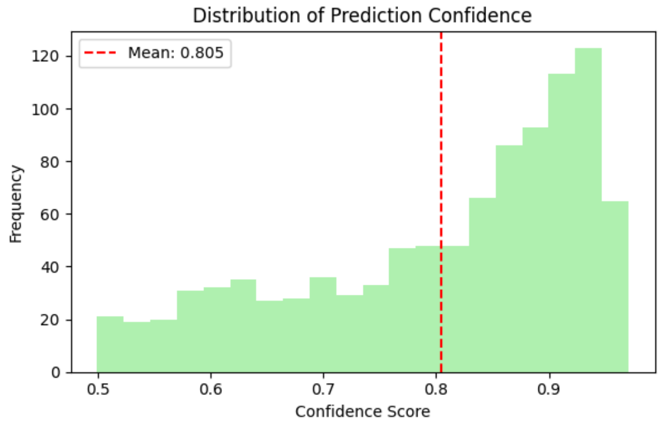
```
📊 Evaluating model performance...
32/32 ━━━━━━━━━━━━━━━━━━━━ 1s 13ms/step
🎯 Model Performance:
Overall Accuracy: 0.8070

📈 Detailed Classification Report:
              precision    recall  f1-score   support

         yes       0.80      0.82      0.81       497
          no       0.82      0.79      0.80       503

    accuracy                           0.81      1000
   macro avg       0.81      0.81      0.81      1000
weighted avg       0.81      0.81      0.81      1000
```






```
📊 Confidence Statistics:
Mean Confidence: 0.8049
Std Confidence: 0.1270
Min Confidence: 0.4995
Max Confidence: 0.9704
🔍 Sample Predictions Analysis:
============================================================
32/32 ━━━━━━━━━━━━━━━━━━━━ 0s 4ms/step

📖 Example 1:
Story: Mary got the milk there . John moved to the bedroom .
Question: Is John in the kitchen ?
True Answer: no
Predicted Answer: no
Confidence: 0.8361
Status: ✅ CORRECT
------------------------------------------------------------
```