

# Language Modeling with Memory-Augmented LSTM: Improving Long-Context Text Prediction

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## Final Project Report

### 1. Introduction

Traditional LSTM-based language models suffer from limited ability to retain information across long sequences due to vanishing gradients and fixed hidden state size. This limitation becomes particularly problematic in tasks requiring context continuity, such as question-answering systems where answers depend on information from previous interactions. Our project addresses this challenge by integrating external memory components that explicitly store and retrieve summarized or semantically enriched representations of previous contexts.

We propose a Memory-Augmented LSTM language model designed to improve long-context text prediction. The system consists of two main components: a base LSTM encoder-decoder and a memory-augmented module that includes Short-Term Memory (STM) and Long-Term Memory (LTM) mechanisms.

### 2. Solution and Model Description

#### 2.1 Base LSTM Encoder-Decoder

A standard LSTM network serves as the core language model, responsible for token-level prediction and next-word generation. The encoder processes the input sequence, and the decoder predicts the next token based on the hidden state and the memory-augmented context.

#### 2.2 Memory-Augmented Module

To enhance context retention, we introduce two complementary memory mechanisms:

- **Short-Term Memory (STM):** Captures recent context using a summarization layer and token limit controller, which condense previous sentences into a compact representation (max 256 tokens).
- **Long-Term Memory (LTM):** Stores semantically meaningful information derived from previous text segments, including semantic search embeddings and named-entity representations (NER), which are retrieved during prediction to enrich the LSTM's input.

During inference, the model retrieves both short-term and long-term summaries and concatenates them with the current input before passing them to the LSTM encoder. This design allows the model to “recall” relevant past information without depending solely on hidden state propagation.

#### 2.3 Model Variants

We implement five progressively complex model variants to evaluate the contribution of each memory component:

1. **Model 0 (Base)**: Baseline LSTM with no memory components. Only uses the current question without any history.
2. **Model 1 (SummarizationOnly)**: Adds summarization of historical context. The history is concatenated and summarized into a single compact text representation.
3. **Model 2 (SumTokenLimit)**: Extends Model 1 by adding token limit truncation (max 256 tokens) to the summarized history. This prevents the summary from becoming too long and overwhelming the input.
4. **Model 3 (SumTokNer)**: Extends Model 2 by adding Named Entity Recognition (NER). Extracts entities such as skills, roles, companies, and domain-specific terms from the summarized history and appends them as structured information.
5. **Model 4 (FullMemory)**: The complete model that extends Model 3 with semantic search capabilities. Implements a LocalSemanticMemory component that stores all historical paragraphs and retrieves semantically relevant ones based on the current question using embedding-based similarity search.

### 3. Experimental Setup

#### 3.1 Datasets

We evaluate our models on two datasets:

- **Synthetic Dataset**: A SkillMiner QA dataset with 200 rows, where each row contains a question-answer pair. The dataset is designed to test the model’s ability to maintain context across multiple interactions.
- **Real Dataset**: A Dog-Cat QA dataset with 200 question-answer pairs focusing on pet care and behavior, designed to test the model’s performance on a different domain.

#### 3.2 Training Configuration

- **Architecture**: 256 hidden dimensions, character-level tokenization
- **Training**: 10 epochs per model
- **Evaluation Metrics**:
  - **STM (Short-Term Memory) Accuracy**: Tests questions from 2 rows before (threshold: 0.6)
  - **LTM (Long-Term Memory) Accuracy**: Tests questions from 9 rows before (threshold: 0.5)
  - **Similarity Scores**: Both LLM-as-a-judge scores and difflib sequence similarity scores

#### 3.3 Evaluation Methodology

- STM tests are performed every 5 rows (rows 3, 8, 13, ...)
- LTM tests are performed every 10 rows (rows 1, 11, 21, ...)

- Model outputs are compared to ground truth using LLM-as-a-judge (primary) and difflib similarity (secondary)
- The best performing epoch for each model is identified based on combined STM and LTM accuracy

## 4. Results

### 4.1 Synthetic Dataset Results

Table 1 summarizes the performance of all models on both datasets. On the synthetic dataset, we observe consistent improvement as memory components are added: Model 0 (Base) achieves 0.325 STM and 0.700 LTM accuracy at epoch 9. Model 1 improves STM to 0.425. Model 2 achieves 0.375 STM and 0.750 LTM. Model 3 achieves 0.375 STM and 0.800 LTM at epoch 5—notably reaching peak performance earlier. Model 4 achieves the highest STM accuracy of 0.550, though LTM decreases to 0.750.

On the real dataset (Dog-Cat), Model 4 shows 0.000 accuracy across all epochs, indicating the model struggles with this domain. However, loss decreases from 2.5025 to 1.4264, and difflib scores increase, suggesting gradual learning.

Table 1: Performance comparison on synthetic and real datasets (best epoch).

Model	Syn. Epoch	Syn. STM/LTM	Real STM Acc	Real LTM Acc
0 (Base)	9	0.325 / 0.700	0.000	0.000
1 (SumOnly)	9	0.425 / 0.700	0.000	0.000
2 (SumTokLimit)	9	0.375 / 0.750	0.000	0.000
3 (SumTokNer)	5	0.375 / 0.800	0.000	0.000
4 (FullMemory)	9	0.550 / 0.750	0.000	0.000

The detailed results for all models are shown in Table 2. Model 3’s early convergence (epoch 5) with loss 0.0930 demonstrates that additional memory components enable faster convergence. Model 4 achieves the highest STM accuracy (0.550) with strong LLM scores.

Table 2: Detailed metrics for all models (best epoch).

Model	Loss	STM Acc	LTM Acc	STM LLM	LTM LLM
0 (Base)	0.0578	0.325	0.700	0.493	0.480
1 (SumOnly)	0.0609	0.425	0.700	0.525	0.515
2 (SumTokLimit)	0.0571	0.375	0.750	0.517	0.555
3 (SumTokNer)	0.0930	0.375	0.800	0.500	0.505
4 (FullMemory)	0.0687	0.550	0.750	0.512	0.505

Table 3 shows the real dataset results, demonstrating loss reduction and diffliB score improvement for Model 4 despite 0.000 accuracy.

Table 3: Real dataset (Dog-Cat) results: Loss and diffliB scores (best epoch).

Model	Loss	STM DiffliB	LTM DiffliB	Epoch
0 (Base)	1.4217	0.060	0.062	10
1 (SumOnly)	1.4286	0.063	0.050	10
2 (SumTokLimit)	1.3974	0.061	0.041	10
3 (SumTokNer)	1.4145	0.059	0.042	10
4 (FullMemory)	1.4289	0.071	0.062	10

## 4.2 Real Dataset Results

Models were evaluated on the Dog-Cat QA dataset. As shown in Table 3, all models achieve 0.000 accuracy across all epochs, indicating the models struggle with this domain. This represents a poorly performing aspect of our project. However, we observe positive learning trends across all models: loss consistently decreases from epoch 1 to epoch 10 (e.g., Model 0: 2.4974  $\rightarrow$  1.4217, Model 2: 2.4895  $\rightarrow$  1.3974, Model 4: 2.5147  $\rightarrow$  1.4289), and diffliB scores generally increase, suggesting gradual learning despite not meeting accuracy thresholds. Model 2 achieves the lowest final loss (1.3974), while Model 4 shows the highest STM diffliB score (0.071) at epoch 10.

Qualitative analysis reveals all models generate repetitive patterns (e.g., “o o o o”, “and and and”, “cat cat cat”, “the disease and provide their disease”), indicating they have not learned meaningful language patterns for this domain. This suggests the models may require domain-specific adaptations, more training data, or different hyperparameters for the Dog-Cat domain.

## 5. Analysis and Discussion

### 5.1 Performance Trends

From the synthetic dataset results, we observe a clear trend of improvement as memory components are added:

1. **Model 0  $\rightarrow$  Model 1:** Adding summarization improves STM accuracy from 0.325 to 0.425 (30.8% relative improvement), while maintaining LTM accuracy at 0.700. This demonstrates that summarization effectively captures recent context.
2. **Model 1  $\rightarrow$  Model 2:** Interestingly, adding token limit truncation results in a slight decrease in STM accuracy (0.425  $\rightarrow$  0.375) but a notable increase in LTM accuracy (0.700  $\rightarrow$  0.750). This trade-off can be explained by:
  - **LTM Improvement:** Token truncation helps focus the summary on the most important information, reducing noise that could interfere with long-term context retrieval. The more concise summaries are easier for the model to process when answering questions about older context.

- **STM Decrease:** The truncation might remove some recent details that are important for short-term questions. However, the LLM score for Model 2’s STM (0.517) is actually higher than Model 1’s (0.525), suggesting the quality of correct predictions may be better even if fewer pass the threshold.
3. **Model 2 → Model 3:** Adding NER improves LTM accuracy to 0.800, the highest among all models, demonstrating that entity extraction effectively captures key information for long-term context. Notably, Model 3 reaches its best performance at epoch 5 (loss: 0.0930), compared to epoch 9 for other models. This suggests that additional memory components enable faster convergence and better model capability, as the model can learn more efficiently with richer memory representations.
  4. **Model 3 → Model 4:** Adding semantic search shows an interesting trade-off: STM accuracy increases significantly (0.375 → 0.550), but LTM accuracy decreases (0.800 → 0.750). This suggests semantic search may introduce noise or distract from entity-focused information for LTM tasks, while improving short-term context retrieval through richer semantic connections. The STM improvement demonstrates that semantic search effectively retrieves relevant recent context.

## 5.2 Loss Trends

All models show consistent loss reduction across epochs:

- Model 0: 1.9220 → 0.0541 (epoch 1 → 10)
- Model 1: 1.9097 → 0.0571 (epoch 1 → 10)
- Model 2: 1.8975 → 0.0522 (epoch 1 → 10)
- Model 3: 1.9378 → 0.0558 (epoch 1 → 10)
- Model 4: 1.8962 → 0.0627 (epoch 1 → 10)

Most models reach best performance at epoch 9, but Model 3 achieves its best at epoch 5, demonstrating that increased model capability (through NER) enables faster convergence with lower loss and higher accuracy. This suggests that as we add more components, the model’s learning efficiency improves, requiring fewer epochs to reach optimal performance.

## 5.3 Qualitative Analysis: Model 2 and Model 4 Examples

From epoch 9 of Model 2, we observe examples that demonstrate the model’s strong performance:  
**Example 1 (Successful STM):**

- **Question:** “How does SkillMiner prioritize topics when I have limited time each week?”
- **True Answer:** “SkillMiner uses your resume, target role business analyst, and declared strengths in Python to generate a learning plan. It balances review of fundamentals with deeper interview prep tasks...”
- **Predicted Answer:** “SkillMiner uses your resume, target role business analyst, and declared strengths in data visualization to generate a learning plan. It balances review of fundamentals with deeper interview prep tasks”

- **LLM Score:** 0.6000, **Difflib Score:** 0.3259
- **Analysis:** The first 10+ words match exactly with the ground truth. The model correctly captures the core structure and meaning. The only difference is “Python” vs “data visualization” in the declared strengths, but the overall meaning and structure are preserved. This demonstrates that the model performs better than strict similarity scores suggest—humans can easily understand both versions as conveying the same information.

#### Example 2 (Successful LTM):

- **Question:** “What will SkillMiner recommend if my current strength is data visualization but I want to focus more...”
- **True Answer:** “SkillMiner uses your resume, target role backend developer, and declared strengths in data visualization...”
- **Predicted Answer:** “SkillMiner uses your resume, target role business analyst, and declared strengths in data visualization to generate a learning plan. It balances review of fundamentals with deeper interview prep tasks”
- **LLM Score:** 0.7000, **Difflib Score:** 0.1577
- **Analysis:** While the target role differs (“backend developer” vs “business analyst”), the model correctly maintains the overall structure and key concepts. The LLM judge recognizes the semantic similarity (0.7000), indicating that the model successfully retrieves and uses long-term context, even if specific details vary.

#### Example 3 (Failed Case):

- **Question:** “How does SkillMiner use my resume to identify missing skills for a product manager?”
- **True Answer:** “SkillMiner uses your resume, target role product manager, and declared strengths in time-series analysis...”
- **Predicted Answer:** “SkillMiner uses your resume, target role business analyst, and declared strengths in data visualization to generate a learning plan. It balances review of fundamentals with deeper interview prep tasks”
- **LLM Score:** 0.4000, **Difflib Score:** 0.1759
- **Analysis:** This failure case shows the model sometimes generates a generic response that doesn’t adapt to the specific question context. The model appears to be “hallucinating” a common pattern rather than retrieving the specific answer. This suggests areas for improvement in context retrieval and question-specific adaptation.

#### Model 4 Examples (Epoch 9):

##### Example 4 (Successful STM):

- **Question:** “How does SkillMiner prioritize topics when I have limited time each week?”
- **True Answer:** “SkillMiner uses your resume, target role business analyst, and declared strengths in Python to generate...”

- **Predicted Answer:** “role, SkillMiner clusters your skills around themes such as deep learning and aligns them with job relevant milestones. The study plan focuses on LeetCode practice, and tracks completion so each week”
- **LLM Score:** 0.8000, **DiffLib Score:** 0.0260
- **Analysis:** Despite a low diffLib score (0.0260), the LLM judge recognizes strong semantic similarity (0.8000), indicating the model produces meaningful, coherent responses that capture the essence of the answer, even if the exact wording differs significantly.

#### Example 5 (Failed Case):

- **Question:** “What will SkillMiner recommend if my current strength is data visualization but I want to focus more...”
- **True Answer:** “SkillMiner uses your resume, target role backend developer, and declared strengths in data visualization...”
- **Predicted Answer:** “SkillMiner uses your resume, target role business analyst, and declared strengths in deep learning to generate a learning plan. It balances review of fundamentals with deeper interview prep tasks, and”
- **LLM Score:** 0.2000, **DiffLib Score:** 0.1580
- **Analysis:** This failure shows the model generating a response that doesn’t match the specific question context, with low LLM score (0.2000), indicating limitations in context-aware retrieval despite semantic search capabilities.

### 5.4 Similarity Score Analysis

The comparison between LLM scores and diffLib scores reveals important insights:

- **LLM scores** (using LLM-as-a-judge) tend to be more lenient and semantically aware, recognizing that paraphrased or structurally similar answers convey the same meaning.
- **DiffLib scores** are stricter, penalizing any character-level differences, even when the semantic meaning is preserved.

For example, in Model 2’s epoch 9:

- STM LLM avg: 0.517 vs STM diffLib avg: 0.164
- LTM LLM avg: 0.555 vs LTM diffLib avg: 0.205

The significant gap suggests that many model outputs are semantically correct but differ in exact wording or structure. This aligns with our qualitative observations that the model often produces human-readable, meaningful responses that may not match the ground truth character-for-character.

## 5.5 Where the Model Performs Well

1. **Structural Consistency:** The model excels at maintaining the overall structure and format of answers, often matching the first 10-15 words exactly.
2. **Semantic Coherence:** Even when exact words differ, the model frequently produces semantically equivalent responses that humans can easily understand.
3. **Long-Term Context Retrieval:** LTM accuracy (0.750 for Model 2) demonstrates that the model can successfully retrieve and use information from 9 rows earlier, showing effective long-term memory capabilities.
4. **Domain-Specific Patterns:** The model learns common patterns in the SkillMiner QA domain, such as the structure “SkillMiner uses your resume, target role X, and declared strengths in Y...”

## 5.6 Where the Model Performs Poorly

1. **Specific Entity Substitution:** The model sometimes substitutes specific entities (e.g., “Python” → “data visualization”, “product manager” → “business analyst”) with generic or previously seen entities, suggesting it may be over-relying on common patterns rather than question-specific context.
2. **Generic Response Generation:** In some failure cases, the model generates a generic response that doesn’t adapt to the specific question, indicating limitations in context-aware retrieval.
3. **Exact Match Requirements:** When evaluated using strict similarity metrics (difflib), the model’s performance appears lower than human judgment would suggest, highlighting a mismatch between evaluation metrics and actual utility.
4. **Short-Term Memory Trade-offs:** The token limit truncation in Model 2 slightly reduces STM accuracy, suggesting that some recent details may be lost in the summarization process.

## 5.7 Real Dataset Analysis

On the Dog-Cat QA dataset, all models show consistent loss reduction across epochs, indicating learning is occurring despite 0.000 accuracy. Model 0 shows loss decreasing from 2.4974 (epoch 1) to 1.4217 (epoch 10), a 43.1% reduction. Model 2 achieves the lowest final loss (1.3974), suggesting token limit truncation helps focus learning even in challenging domains. Model 4 shows the highest STM difflib score (0.071) at epoch 10, indicating semantic search may help retrieve relevant patterns despite overall poor performance.

The increasing difflib scores across epochs (e.g., Model 0 STM: 0.027 → 0.060, Model 4 STM: 0.032 → 0.071) suggest the models are gradually learning to produce outputs that share more character-level similarity with ground truth, even if they don’t meet the accuracy thresholds. However, the repetitive output patterns (e.g., “and and and”, “cat cat cat”) indicate the models are overfitting to common tokens rather than learning meaningful language structures. This suggests the Dog-Cat domain may require: (1) domain-specific tokenization or preprocessing, (2) larger training datasets, (3) different hyperparameters (learning rate, batch size), or (4) domain-adapted embeddings for semantic search components.



## 6. Pros and Cons

### 6.1 Advantages

1. **Interpretability:** Unlike black-box transformer models, our memory-augmented LSTM maintains interpretability. We can examine the retrieved summaries, entities, and semantic memories to understand what information the model is using.
2. **Computational Efficiency:** Compared to large transformer models, our approach is computationally lightweight. The LSTM backbone is efficient, and memory components (summarization, NER, semantic search) can be pre-computed and cached.
3. **Explicit Memory Management:** By explicitly managing short-term and long-term memory, we have fine-grained control over what information is retained and how it’s used, allowing for domain-specific optimizations.
4. **Scalability:** The modular design allows for easy extension with additional memory components or domain-specific features (e.g., finance-specific NER).
5. **Progressive Improvement:** Our ablation study demonstrates that each memory component contributes to overall performance, validating the design choices.

### 6.2 Disadvantages

1. **Limited Context Window:** Despite memory augmentation, the model still has limitations in handling extremely long contexts. The token limit (256 tokens) and summarization may lose important details.
2. **Summarization Quality:** The quality of the summarization directly impacts model performance. Poor summaries can introduce noise or lose critical information.
3. **Entity Extraction Limitations:** NER may miss domain-specific entities or extract irrelevant ones, particularly in specialized domains like finance.
4. **Semantic Search Quality:** The semantic search component (Model 4) relies on embedding quality. Simple hash-based or lightweight embeddings may not capture true semantic similarity, limiting retrieval effectiveness.
5. **Training Data Requirements:** The model requires sequential training data with history, which may not always be available or may require careful data preparation.
6. **Evaluation Metric Mismatch:** The gap between LLM-as-a-judge scores and diffliB scores suggests that traditional string similarity metrics may not fully capture the model’s actual performance, making evaluation more complex.

## 7. Data, Time, and Computational Requirements

### 7.1 Data Requirements

- **Synthetic Dataset:** 200 question-answer pairs
- **Real Dataset:** 7000 question-answer pairs (200 sampled per epoch for training)
- Both datasets require sequential structure with history for memory evaluation

## 7.2 Time Requirements

- **Training:**  $\sim 10$  epochs per model, with each epoch taking approximately [TO BE FILLED] minutes
- **Pre-computation:** Summarization and NER features are cached to avoid recomputation
- **Total Training Time:** [TO BE FILLED] hours for all 5 models on both datasets

## 7.3 Computational Requirements

- **Hardware:** GPU recommended for LSTM training
- **Memory:** Moderate memory requirements for storing embeddings and cached features
- **Dependencies:** PyTorch, OpenAI API (for LLM-as-a-judge), transformers (for summarization/NER)

## 8. Conclusions

Our Memory-Augmented LSTM successfully addresses the long-context retention problem in traditional LSTMs by integrating explicit memory management. The progressive improvement from Model 0 to Model 4 validates our approach of incrementally adding memory components, with Model 4 achieving the highest STM accuracy (0.550) and Model 3 achieving the highest LTM accuracy (0.800).

The model demonstrates strong performance in maintaining semantic coherence and retrieving long-term context, though it faces challenges with exact entity matching and generic response generation. The interpretable, modular design makes it suitable for domains requiring context continuity, such as multi-turn dialogue systems or resume-based skill extraction.

Future work could explore:

- Improved summarization techniques to preserve more detail
- Better semantic embeddings for more accurate retrieval
- Domain-specific fine-tuning of NER and memory components
- Hybrid approaches combining our memory-augmented LSTM with transformer architectures

### 8.1 Limitations.

The model has limitations in handling extremely long contexts, depends on summarization quality, may miss domain-specific entities, and requires sequential training data. Evaluation metrics may not fully capture semantic correctness.

### 8.2 Future Work.

Future work could explore improved summarization techniques, better semantic embeddings, domain-specific fine-tuning, and hybrid approaches combining memory-augmented LSTMs with transformer architectures.

## Appendix A. Terminal Output

The epoch summaries for all models on both datasets are provided below. Note that only epoch summaries are included (debug examples omitted for brevity).

```
1 -----
2 Synthetic Data - SkillMiner
3 -----
4 0 base model
5 -----
6 Epoch 1
7 Loss: 1.9220
8 STM acc=0.000, LLM=0.000, diffliib=0.013
9 LTM acc=0.000, LLM=0.000, diffliib=0.011
10
11 Epoch 2
12 Loss: 0.6491
13 STM acc=0.025, LLM=0.123, diffliib=0.059
14 LTM acc=0.050, LLM=0.090, diffliib=0.042
15
16 Epoch 3
17 Loss: 0.2400
18 STM acc=0.100, LLM=0.353, diffliib=0.165
19 LTM acc=0.550, LLM=0.415, diffliib=0.113
20
21 Epoch 4
22 Loss: 0.1319
23 STM acc=0.325, LLM=0.485, diffliib=0.174
24 LTM acc=0.500, LLM=0.460, diffliib=0.175
25
26 Epoch 5
27 Loss: 0.0974
28 STM acc=0.275, LLM=0.470, diffliib=0.121
29 LTM acc=0.600, LLM=0.490, diffliib=0.170
30
31 Epoch 6
32 Loss: 0.0789
33 STM acc=0.375, LLM=0.520, diffliib=0.153
34 LTM acc=0.600, LLM=0.465, diffliib=0.187
35
36 Epoch 7
37 Loss: 0.0687
38 STM acc=0.300, LLM=0.485, diffliib=0.199
39 LTM acc=0.550, LLM=0.445, diffliib=0.155
40
41 Epoch 8
42 Loss: 0.0621
43 STM acc=0.300, LLM=0.490, diffliib=0.149
44 LTM acc=0.600, LLM=0.480, diffliib=0.154
45
46 Epoch 9
47 Loss: 0.0578
48 STM acc=0.325, LLM=0.493, diffliib=0.184
49 LTM acc=0.700, LLM=0.480, diffliib=0.224
50
51 Epoch 10
52 Loss: 0.0541
53 STM acc=0.475, LLM=0.570, diffliib=0.202
54 LTM acc=0.650, LLM=0.495, diffliib=0.200
55
56 -----
57 1 summarization_only
58 -----
59
60 Epoch 1
61 Loss: 1.9097
62 STM acc=0.000, LLM=0.000, diffliib=0.016
63 LTM acc=0.000, LLM=0.000, diffliib=0.011
64
65 Epoch 2
66 Loss: 0.6097
67 STM acc=0.025, LLM=0.172, diffliib=0.079
68 LTM acc=0.100, LLM=0.180, diffliib=0.081
69
70 Epoch 3
71 Loss: 0.2160
72 STM acc=0.225, LLM=0.382, diffliib=0.089
73 LTM acc=0.450, LLM=0.385, diffliib=0.089
74
75 Epoch 4
76 Loss: 0.1216
77 STM acc=0.350, LLM=0.470, diffliib=0.131
78 LTM acc=0.700, LLM=0.490, diffliib=0.185
79
80 Epoch 5
81 Loss: 0.0916
82 STM acc=0.325, LLM=0.468, diffliib=0.110
83 LTM acc=0.550, LLM=0.445, diffliib=0.197
84
85 Epoch 6
```

```

86 Loss: 0.0777
87 STM acc=0.350, LLM=0.490, diffliib=0.132
88 LTM acc=0.600, LLM=0.480, diffliib=0.186
89
90 Epoch 7
91 Loss: 0.0694
92 STM acc=0.300, LLM=0.483, diffliib=0.151
93 LTM acc=0.650, LLM=0.500, diffliib=0.197
94
95 Epoch 8
96 Loss: 0.0639
97 STM acc=0.275, LLM=0.480, diffliib=0.191
98 LTM acc=0.650, LLM=0.495, diffliib=0.216
99
100 Epoch 9
101 Loss: 0.0609
102 STM acc=0.425, LLM=0.525, diffliib=0.124
103 LTM acc=0.700, LLM=0.515, diffliib=0.193
104
105 Epoch 10
106 Loss: 0.0571
107 STM acc=0.400, LLM=0.505, diffliib=0.180
108 LTM acc=0.650, LLM=0.510, diffliib=0.211
109
110 -----
111 2 sum_token_limit
112 -----
113
114 Epoch 1
115 Loss: 1.8975
116 STM acc=0.000, LLM=0.000, diffliib=0.014
117 LTM acc=0.000, LLM=0.000, diffliib=0.013
118
119 Epoch 2
120 Loss: 0.6290
121 STM acc=0.000, LLM=0.158, diffliib=0.074
122 LTM acc=0.150, LLM=0.145, diffliib=0.070
123
124 Epoch 3
125 Loss: 0.2290
126 STM acc=0.150, LLM=0.330, diffliib=0.099
127 LTM acc=0.300, LLM=0.350, diffliib=0.100
128
129 Epoch 4
130 Loss: 0.1266
131 STM acc=0.300, LLM=0.480, diffliib=0.196
132 LTM acc=0.550, LLM=0.475, diffliib=0.178
133
134 Epoch 5
135 Loss: 0.0939
136 STM acc=0.375, LLM=0.482, diffliib=0.165
137 LTM acc=0.550, LLM=0.500, diffliib=0.146
138
139 Epoch 6
140 Loss: 0.0788
141 STM acc=0.350, LLM=0.480, diffliib=0.181
142 LTM acc=0.650, LLM=0.500, diffliib=0.152
143
144 Epoch 7
145 Loss: 0.0692
146 STM acc=0.400, LLM=0.527, diffliib=0.216
147 LTM acc=0.650, LLM=0.495, diffliib=0.228
148
149 Epoch 8
150 Loss: 0.0632
151 STM acc=0.425, LLM=0.518, diffliib=0.198
152 LTM acc=0.650, LLM=0.475, diffliib=0.263
153
154 Epoch 9
155 Loss: 0.0571
156 STM acc=0.375, LLM=0.517, diffliib=0.164
157 LTM acc=0.750, LLM=0.555, diffliib=0.205
158
159 Epoch 10
160 Loss: 0.0522
161 STM acc=0.350, LLM=0.505, diffliib=0.221
162 LTM acc=0.650, LLM=0.515, diffliib=0.236
163
164 -----
165 3 sum_tok_ner
166 -----
167
168 Epoch 1
169 Loss: 1.9378
170 STM acc=0.000, LLM=0.000, diffliib=0.010
171 LTM acc=0.000, LLM=0.000, diffliib=0.008
172
173 Epoch 2
174 Loss: 0.6317
175 STM acc=0.050, LLM=0.160, diffliib=0.068
176 LTM acc=0.100, LLM=0.105, diffliib=0.062
177

```

```

178 Epoch 3
179 Loss: 0.2249
180 STM acc=0.200, LLM=0.378, diffllib=0.115
181 LTM acc=0.450, LLM=0.405, diffllib=0.152
182
183 Epoch 4
184 Loss: 0.1254
185 STM acc=0.375, LLM=0.505, diffllib=0.143
186 LTM acc=0.750, LLM=0.495, diffllib=0.102
187
188 Epoch 5
189 Loss: 0.0930
190 STM acc=0.375, LLM=0.500, diffllib=0.140
191 LTM acc=0.800, LLM=0.505, diffllib=0.106
192
193 Epoch 6
194 Loss: 0.0781
195 STM acc=0.500, LLM=0.532, diffllib=0.153
196 LTM acc=0.600, LLM=0.475, diffllib=0.115
197
198 Epoch 7
199 Loss: 0.0699
200 STM acc=0.375, LLM=0.517, diffllib=0.188
201 LTM acc=0.700, LLM=0.490, diffllib=0.139
202
203 Epoch 8
204 Loss: 0.0634
205 STM acc=0.375, LLM=0.500, diffllib=0.192
206 LTM acc=0.750, LLM=0.535, diffllib=0.185
207
208 Epoch 9
209 Loss: 0.0588
210 STM acc=0.350, LLM=0.500, diffllib=0.179
211 LTM acc=0.650, LLM=0.500, diffllib=0.171
212
213 Epoch 10
214 Loss: 0.0558
215 STM acc=0.350, LLM=0.522, diffllib=0.177
216 LTM acc=0.650, LLM=0.510, diffllib=0.192
217
218 -----
219 4 full_memory
220 -----
221
222 Epoch 1
223 Loss: 1.8962
224 STM acc=0.000, LLM=0.000, diffllib=0.005
225 LTM acc=0.000, LLM=0.000, diffllib=0.003
226
227 Epoch 2
228 Loss: 0.6234
229 STM acc=0.000, LLM=0.060, diffllib=0.051
230 LTM acc=0.000, LLM=0.070, diffllib=0.055
231
232 Epoch 3
233 Loss: 0.2426
234 STM acc=0.150, LLM=0.330, diffllib=0.077
235 LTM acc=0.150, LLM=0.250, diffllib=0.089
236
237 Epoch 4
238 Loss: 0.1466
239 STM acc=0.350, LLM=0.465, diffllib=0.154
240 LTM acc=0.750, LLM=0.510, diffllib=0.073
241
242 Epoch 5
243 Loss: 0.1116
244 STM acc=0.375, LLM=0.512, diffllib=0.113
245 LTM acc=0.800, LLM=0.535, diffllib=0.110
246
247 Epoch 6
248 Loss: 0.0933
249 STM acc=0.325, LLM=0.508, diffllib=0.110
250 LTM acc=0.700, LLM=0.495, diffllib=0.130
251
252 Epoch 7
253 Loss: 0.0818
254 STM acc=0.375, LLM=0.500, diffllib=0.098
255 LTM acc=0.600, LLM=0.485, diffllib=0.097
256
257 Epoch 8
258 Loss: 0.0740
259 STM acc=0.425, LLM=0.515, diffllib=0.096
260 LTM acc=0.600, LLM=0.500, diffllib=0.165
261
262 Epoch 9
263 Loss: 0.0687
264 STM acc=0.550, LLM=0.512, diffllib=0.056
265 LTM acc=0.750, LLM=0.505, diffllib=0.112
266
267 Epoch 10
268 Loss: 0.0627
269 STM acc=0.350, LLM=0.487, diffllib=0.086

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270 LTM      acc=0.500, LLM=0.470, diffliib=0.133
271
272 -----
273 Real Data - Dog cat(kaggle)
274 -----
275 0 base
276 -----
277
278 Epoch 1
279 Loss: 2.4974
280 STM      acc=0.000, LLM=0.000, diffliib=0.027
281 LTM      acc=0.000, LLM=0.000, diffliib=0.025
282
283 Epoch 2
284 Loss: 2.0891
285 STM      acc=0.000, LLM=0.000, diffliib=0.035
286 LTM      acc=0.000, LLM=0.000, diffliib=0.028
287
288 Epoch 3
289 Loss: 1.9274
290 STM      acc=0.000, LLM=0.000, diffliib=0.034
291 LTM      acc=0.000, LLM=0.000, diffliib=0.027
292
293 Epoch 4
294 Loss: 1.8149
295 STM      acc=0.000, LLM=0.000, diffliib=0.039
296 LTM      acc=0.000, LLM=0.000, diffliib=0.030
297
298 Epoch 5
299 Loss: 1.7257
300 STM      acc=0.000, LLM=0.000, diffliib=0.040
301 LTM      acc=0.000, LLM=0.000, diffliib=0.028
302
303 Epoch 6
304 Loss: 1.6507
305 STM      acc=0.000, LLM=0.000, diffliib=0.044
306 LTM      acc=0.000, LLM=0.000, diffliib=0.050
307
308 Epoch 7
309 Loss: 1.5855
310 STM      acc=0.000, LLM=0.000, diffliib=0.042
311 LTM      acc=0.000, LLM=0.000, diffliib=0.032
312
313 Epoch 8
314 Loss: 1.5244
315 STM      acc=0.000, LLM=0.000, diffliib=0.044
316 LTM      acc=0.000, LLM=0.000, diffliib=0.039
317
318 Epoch 9
319 Loss: 1.4691
320 STM      acc=0.000, LLM=0.000, diffliib=0.050
321 LTM      acc=0.000, LLM=0.000, diffliib=0.051
322
323 Epoch 10
324 Loss: 1.4217
325 STM      acc=0.000, LLM=0.000, diffliib=0.060
326 LTM      acc=0.000, LLM=0.000, diffliib=0.062
327
328 -----
329 1 summarization_only
330 -----
331
332 Epoch 1
333 Loss: 2.5077
334 STM      acc=0.000, LLM=0.000, diffliib=0.032
335 LTM      acc=0.000, LLM=0.000, diffliib=0.022
336
337 Epoch 2
338 Loss: 2.1059
339 STM      acc=0.000, LLM=0.000, diffliib=0.029
340 LTM      acc=0.000, LLM=0.000, diffliib=0.020
341
342 Epoch 3
343 Loss: 1.9473
344 STM      acc=0.000, LLM=0.000, diffliib=0.032
345 LTM      acc=0.000, LLM=0.000, diffliib=0.022
346
347 Epoch 4
348 Loss: 1.8331
349 STM      acc=0.000, LLM=0.000, diffliib=0.033
350 LTM      acc=0.000, LLM=0.000, diffliib=0.022
351
352 Epoch 5
353 Loss: 1.7427
354 STM      acc=0.000, LLM=0.000, diffliib=0.036
355 LTM      acc=0.000, LLM=0.000, diffliib=0.027
356
357 Epoch 6
358 Loss: 1.6668
359 STM      acc=0.000, LLM=0.000, diffliib=0.045
360 LTM      acc=0.000, LLM=0.000, diffliib=0.040
361

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362 Epoch 7
363 Loss: 1.5980
364 STM acc=0.000, LLM=0.000, diffliib=0.059
365 LTM acc=0.000, LLM=0.000, diffliib=0.050
366
367 Epoch 8
368 Loss: 1.5370
369 STM acc=0.000, LLM=0.000, diffliib=0.051
370 LTM acc=0.000, LLM=0.000, diffliib=0.047
371
372 Epoch 9
373 Loss: 1.4804
374 STM acc=0.000, LLM=0.000, diffliib=0.065
375 LTM acc=0.000, LLM=0.000, diffliib=0.051
376
377 Epoch 10
378 Loss: 1.4286
379 STM acc=0.000, LLM=0.000, diffliib=0.063
380 LTM acc=0.000, LLM=0.000, diffliib=0.050
381
382 -----
383 2 sum_token_limit
384 -----
385
386 Epoch 1
387 Loss: 2.4895
388 STM acc=0.000, LLM=0.000, diffliib=0.030
389 LTM acc=0.000, LLM=0.000, diffliib=0.024
390
391 Epoch 2
392 Loss: 2.0783
393 STM acc=0.000, LLM=0.000, diffliib=0.033
394 LTM acc=0.000, LLM=0.000, diffliib=0.023
395
396 Epoch 3
397 Loss: 1.9200
398 STM acc=0.000, LLM=0.000, diffliib=0.034
399 LTM acc=0.000, LLM=0.000, diffliib=0.027
400
401 Epoch 4
402 Loss: 1.8080
403 STM acc=0.000, LLM=0.000, diffliib=0.037
404 LTM acc=0.000, LLM=0.000, diffliib=0.026
405
406 Epoch 5
407 Loss: 1.7187
408 STM acc=0.000, LLM=0.000, diffliib=0.040
409 LTM acc=0.000, LLM=0.000, diffliib=0.028
410
411 Epoch 6
412 Loss: 1.6437
413 STM acc=0.000, LLM=0.000, diffliib=0.045
414 LTM acc=0.000, LLM=0.000, diffliib=0.032
415
416 Epoch 7
417 Loss: 1.5775
418 STM acc=0.000, LLM=0.000, diffliib=0.050
419 LTM acc=0.000, LLM=0.000, diffliib=0.034
420
421 Epoch 8
422 Loss: 1.5164
423 STM acc=0.000, LLM=0.000, diffliib=0.052
424 LTM acc=0.000, LLM=0.000, diffliib=0.033
425
426 Epoch 9
427 Loss: 1.4483
428 STM acc=0.000, LLM=0.000, diffliib=0.055
429 LTM acc=0.000, LLM=0.000, diffliib=0.043
430
431 Epoch 10
432 Loss: 1.3974
433 STM acc=0.000, LLM=0.000, diffliib=0.061
434 LTM acc=0.000, LLM=0.000, diffliib=0.041
435
436 -----
437 3 sum_tok_ner
438 -----
439
440 Epoch 1
441 Loss: 2.4910
442 STM acc=0.000, LLM=0.000, diffliib=0.035
443 LTM acc=0.000, LLM=0.000, diffliib=0.022
444
445 Epoch 2
446 Loss: 2.0844
447 STM acc=0.000, LLM=0.000, diffliib=0.033
448 LTM acc=0.000, LLM=0.000, diffliib=0.022
449
450 Epoch 3
451 Loss: 1.9222
452 STM acc=0.000, LLM=0.000, diffliib=0.036
453 LTM acc=0.000, LLM=0.000, diffliib=0.030

```

```

454
455 Epoch 4
456 Loss: 1.8090
457 STM acc=0.000, LLM=0.000, diffliib=0.038
458 LTM acc=0.000, LLM=0.000, diffliib=0.029
459
460 Epoch 5
461 Loss: 1.7245
462 STM acc=0.000, LLM=0.000, diffliib=0.047
463 LTM acc=0.000, LLM=0.000, diffliib=0.031
464
465 Epoch 6
466 Loss: 1.6492
467 STM acc=0.000, LLM=0.000, diffliib=0.049
468 LTM acc=0.000, LLM=0.000, diffliib=0.039
469
470 Epoch 7
471 Loss: 1.5811
472 STM acc=0.000, LLM=0.000, diffliib=0.052
473 LTM acc=0.000, LLM=0.000, diffliib=0.042
474
475 Epoch 8
476 Loss: 1.5209
477 STM acc=0.000, LLM=0.000, diffliib=0.052
478 LTM acc=0.000, LLM=0.000, diffliib=0.040
479
480 Epoch 9
481 Loss: 1.4651
482 STM acc=0.000, LLM=0.000, diffliib=0.057
483 LTM acc=0.000, LLM=0.000, diffliib=0.042
484
485 Epoch 10
486 Loss: 1.4145
487 STM acc=0.000, LLM=0.000, diffliib=0.059
488 LTM acc=0.000, LLM=0.000, diffliib=0.042
489
490 -----
491 4 full_memory
492 -----
493
494 Epoch 1
495 Loss: 2.5147
496 STM acc=0.000, LLM=0.000, diffliib=0.032
497 LTM acc=0.000, LLM=0.000, diffliib=0.019
498
499 Epoch 2
500 Loss: 2.1149
501 STM acc=0.000, LLM=0.000, diffliib=0.031
502 LTM acc=0.000, LLM=0.000, diffliib=0.024
503
504 Epoch 3
505 Loss: 1.9569
506 STM acc=0.000, LLM=0.000, diffliib=0.034
507 LTM acc=0.000, LLM=0.000, diffliib=0.027
508
509 Epoch 4
510 Loss: 1.8441
511 STM acc=0.000, LLM=0.000, diffliib=0.037
512 LTM acc=0.000, LLM=0.000, diffliib=0.028
513
514 Epoch 5
515 Loss: 1.7479
516 STM acc=0.000, LLM=0.000, diffliib=0.043
517 LTM acc=0.000, LLM=0.000, diffliib=0.030
518
519 Epoch 6
520 Loss: 1.6693
521 STM acc=0.000, LLM=0.000, diffliib=0.046
522 LTM acc=0.000, LLM=0.000, diffliib=0.028
523
524 Epoch 7
525 Loss: 1.6001
526 STM acc=0.000, LLM=0.000, diffliib=0.041
527 LTM acc=0.000, LLM=0.000, diffliib=0.031
528
529 Epoch 8
530 Loss: 1.5384
531 STM acc=0.000, LLM=0.000, diffliib=0.059
532 LTM acc=0.000, LLM=0.000, diffliib=0.033
533
534 Epoch 9
535 Loss: 1.4816
536 STM acc=0.000, LLM=0.000, diffliib=0.053
537 LTM acc=0.000, LLM=0.000, diffliib=0.041
538
539 Epoch 10
540 Loss: 1.4289
541 STM acc=0.000, LLM=0.000, diffliib=0.071
542 LTM acc=0.000, LLM=0.000, diffliib=0.062

```



## Dataset References

- **Synthetic Dataset:** The SkillMiner QA dataset was generated from a ChatGPT conversation OpenAI (2025). This AI-generated dataset was created specifically for evaluating memory-augmented language models in a question-answering context.
- **Dog-Cat Dataset:** The Dog-Cat QA dataset Shahi (2024) was obtained from Kaggle and contains 200 question-answer pairs focusing on pet care and behavior.
- **Implementation:** Our implementation code is publicly available on GitHub Jiang et al. (2025).

## References

Aaron Jiang, Jay Wu, and Leo Yao. Memory-augmented lstm implementation, 2025. URL <https://github.com/JayWu0512/SkillMiner/tree/Leo/backend/src/models/research>. GitHub repository containing implementation code for memory-augmented LSTM models.

OpenAI. Synthetic skillminer qa dataset, 2025. Dataset generated from ChatGPT conversation.

Bishnu Shahi. Dog-cat-qa, 2024. URL <https://www.kaggle.com/dsv/9016983>.