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# TELEPATHY: CROSS-MODEL COMMUNICATION VIA SOFT TOKENS

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## ABSTRACT

We present Telepathy, a method for enabling communication between heterogeneous large language models (LLMs) through learned soft tokens, bypassing autoregressive text generation entirely. Our approach uses a lightweight Perceiver Resampler bridge (188K parameters) to transform hidden states from a sender model (Llama 3.1 8B) into soft tokens that directly condition a receiver model (Mistral 7B). On text classification benchmarks, Telepathy achieves **22.4× lower latency** than text-relay baselines while exceeding task accuracy. The bridge outperforms full fine-tuning (**+2.7pp with 5300× fewer parameters**), LoRA (+1.4pp with 18× fewer parameters), 5-shot prompting (+2.2–59pp), and chain-of-thought relay (+7.7pp while being 85× faster). Critically, prompt-tuning on Mistral alone achieves only random chance (49.5% on SST-2), while the bridge achieves **96.7%**—proving the sender model’s hidden states are essential. Surprisingly, **cross-model transfer outperforms same-model transfer** (Llama→Mistral: 96.7% vs. Llama→Llama: 84.5%), suggesting heterogeneous models provide complementary information. We observe **super-additive performance**: the bridge exceeds both Llama (92.0%) and Mistral (88.5%) operating independently. These findings demonstrate that cross-model communication via continuous representations can be both faster and more effective than discrete text for classification tasks.

## 1 INTRODUCTION

Large language models (LLMs) have emerged as powerful tools for natural language understanding and generation (Vaswani et al., 2017; Touvron et al., 2023; Jiang et al., 2023a). However, the dominant paradigm for combining multiple LLMs involves sequential text generation: one model produces text that another model consumes. This approach incurs substantial latency due to autoregressive decoding and may lose information through the discretization bottleneck of natural language.

We propose **Telepathy**, a method that enables direct communication between heterogeneous LLMs through learned soft tokens. Rather than having a sender model generate text for a receiver model to process, Telepathy transforms the sender’s internal representations into a small set of continuous embeddings (soft tokens) that directly condition the receiver model’s inference. This approach:

1. **Eliminates autoregressive generation latency:** The sender model only performs a single forward pass, reducing end-to-end latency by over 20× compared to text-relay approaches.

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2. **Preserves continuous information:** Soft tokens can encode nuances that may be lost when discretizing to natural language tokens.
3. **Enables super-additive performance:** The combined system can outperform either model operating independently, suggesting emergent capabilities from cross-model communication.

Our key contributions are:

- A lightweight bridge architecture based on Perceiver Resampler (Jaegle et al., 2021; Alayrac et al., 2022) that transforms hidden states between heterogeneous LLMs with only 188K trainable parameters.
- Comprehensive evaluation against strong baselines (5-shot prompting, LoRA, chain-of-thought) showing the bridge outperforms all approaches in accuracy and/or efficiency.
- Analysis of an inverse scaling phenomenon where compression to fewer soft tokens improves rather than degrades performance.
- Latency and throughput benchmarks showing 22–85× speedup over text-based communication, scaling to 100+ samples/second.

## 055 2 RELATED WORK

056 **Soft Prompts and Prompt Tuning** Prompt tuning  
 057 (Lester et al., 2021) and prefix tuning (Li & Liang, 2021)  
 058 demonstrated that freezing LLM weights while learning  
 059 continuous “soft” prompt embeddings can match full fine-  
 060 tuning performance. Our work extends this paradigm from  
 061 single-model adaptation to cross-model communication, us-  
 062 ing soft tokens as an interlingua between heterogeneous  
 063 models.

064  
 065 **Perceiver Architecture** The Perceiver (Jaegle et al.,  
 066 2021) introduced cross-attention to map arbitrary-length  
 067 inputs to a fixed-size latent array, enabling efficient pro-  
 068 cessing of diverse modalities. Perceiver IO extended this  
 069 to arbitrary outputs. Our bridge architecture draws from  
 070 this design, using cross-attention to compress sender hidden  
 071 states into a small number of soft tokens.

072  
 073 **Vision-Language Models** BLIP-2 (Li et al., 2023) intro-  
 074 duced the Q-Former, a lightweight transformer that bridges  
 075 frozen image encoders and frozen LLMs through learned  
 076 query tokens. Flamingo (Alayrac et al., 2022) similarly  
 077 used a Perceiver Resampler to map visual features to soft  
 078 prompts for LLM conditioning. Our work applies similar  
 079 architectural principles to bridge two language models rather  
 080 than vision and language modalities.

081  
 082 **Model Stitching and Knowledge Transfer** Model stitching  
 083 (Bansal et al., 2021; Pan et al., 2023) connects layers  
 084 from different networks using learned transformations. Re-  
 085 cent work shows that affine mappings between residual  
 086 streams can transfer features across models (Anonymous,  
 087 2024b), and StitchLLM (Anonymous, 2025b) introduces  
 088 stitching layers for adaptive model composition. Cross-  
 089 LoRA (Anonymous, 2024a) enables data-free transfer of  
 090 LoRA adapters between heterogeneous LLMs. Prompt-  
 091 Bridge (Liu et al., 2024) addresses prompt transferabil-  
 092 ity across models. Our approach differs by enabling run-  
 093 time communication through soft tokens rather than offline  
 094 weight transfer.

095  
 096 **Multi-Agent LLM Systems** Recent work on multi-agent  
 097 systems (Anonymous, 2025a; Wu et al., 2023) explores col-  
 098 laboration between multiple LLMs through natural language  
 099 communication. While effective, text-based communication  
 100 incurs latency from autoregressive generation. Telepathy  
 101 provides a faster alternative through continuous representa-  
 102 tions.

103  
 104 **Prompt Compression** Methods like LLMLingua (Jiang  
 105 et al., 2023b) compress prompts by removing tokens while  
 106 preserving task performance. Soft prompt methods like  
 107 ICAE (Ge et al., 2024) and 500xCompressor (Li et al., 2024)

108 learn to compress context into dense embeddings. Recent  
 109 work (Xu et al., 2024) shows soft prompts can recover com-  
 110 pressed LLM performance and transfer across models. Our  
 111 work focuses on cross-model communication rather than  
 112 single-model compression.

## 3 METHOD

### 3.1 Problem Formulation

We formalize the cross-model communication problem as follows. Let  $\mathcal{S}$  and  $\mathcal{R}$  denote a sender and receiver LLM respectively, with potentially different architectures, tokenizers, and training distributions. Given input text  $x$ , we seek a communication protocol that enables  $\mathcal{R}$  to perform a downstream task using information extracted from  $\mathcal{S}$ ’s processing of  $x$ .

**Desiderata** An ideal cross-model communication mechanism should satisfy:

1. **Efficiency:** Communication should be faster than text generation ( $O(1)$  vs  $O(L)$  autoregressive steps).
2. **Fidelity:** Task-relevant information should be pre-  
served through the channel.
3. **Modularity:** Both models remain frozen; only the  
communication channel is learned.
4. **Compression:** The transmitted representation should  
be compact ( $M \ll L$  tokens).

**Formal Setup** Let  $\mathbf{h}_\mathcal{S}^{(\ell)} \in \mathbb{R}^{L \times d_\mathcal{S}}$  denote the hidden states from layer  $\ell$  of the sender, where  $L$  is the sequence length and  $d_\mathcal{S}$  is the hidden dimension. We seek a bridge function  $f_\theta : \mathbb{R}^{L \times d_\mathcal{S}} \rightarrow \mathbb{R}^{M \times d_\mathcal{R}}$  that produces soft tokens  $\mathbf{z} = f_\theta(\mathbf{h}_\mathcal{S}^{(\ell)})$  satisfying:

$$\mathbf{z}^* = \arg \max_{\mathbf{z}} p_{\mathcal{R}}(y | \mathbf{z}, \mathbf{x}_{\text{prompt}}) \quad (1)$$

where  $y$  is the correct task output and  $\mathbf{x}_{\text{prompt}}$  is an optional task-specific prompt.

**Key Challenge: Representation Mismatch** The sender and receiver occupy different representation spaces. Even when hidden dimensions match ( $d_\mathcal{S} = d_\mathcal{R} = 4096$  for Llama and Mistral), the geometric structure differs due to:

- **Vocabulary:** Llama (128K tokens) vs. Mistral (32K tokens)
- **Positional encoding:** Different RoPE base frequencies
- **Attention:** Grouped-query (Llama) vs. sliding win-  
dow (Mistral)

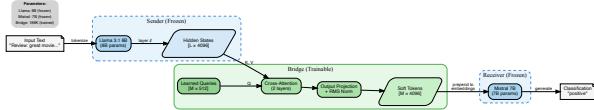


Figure 1. Telepathy architecture. Input text is processed by the frozen sender (Llama), whose hidden states are transformed by the lightweight bridge (188K params) into soft tokens that condition the frozen receiver (Mistral) for classification.

- **Statistics:** Hidden state magnitude differs by  $\sim 5 \times$

A naive linear projection fails because it assumes isomorphic spaces. The bridge must learn a *semantic translation*, not merely a coordinate transformation. Figure 1 illustrates the overall pipeline.

### 3.2 Bridge Architecture

Our bridge uses a Perceiver Resampler design:

1. **Input Projection:** Linear projection from sender hidden dimension to bridge internal dimension:  $\mathbf{h}' = \mathbf{W}_{\text{in}} \mathbf{h}_S$ , where  $\mathbf{W}_{\text{in}} \in \mathbb{R}^{d_S \times d}$ .
2. **Learned Latent Queries:** A set of  $M$  learnable query vectors  $\mathbf{Q} \in \mathbb{R}^{M \times d}$  that attend to the projected sender states.
3. **Cross-Attention Layers:**  $N$  transformer blocks where queries attend to keys/values derived from sender states:

$$\mathbf{z}^{(n+1)} = \text{FFN}(\text{CrossAttn}(\mathbf{z}^{(n)}, \mathbf{h}')) \quad (2)$$

We use  $N = 2$  layers with  $d = 512$  internal dimension.

4. **Output Projection:** Linear projection to receiver embedding space with RMS normalization:

$$\mathbf{z} = \alpha \cdot \frac{\mathbf{W}_{\text{out}} \mathbf{z}^{(N)}}{\text{RMS}(\mathbf{W}_{\text{out}} \mathbf{z}^{(N)})} \quad (3)$$

where  $\alpha$  is calibrated to match the receiver’s embedding statistics.

The total parameter count is approximately 188K, negligible compared to the frozen 8B+7B models.

### 3.3 Design Space: Why Cross-Attention?

The bridge architecture was not obvious *a priori*. We systematically explored several design alternatives before arriving at the Perceiver-based approach. This section documents the design space and explains why certain choices work while others fail.

Architecture	SST-2 Acc.	Verdict
Perceiver (ours)	<b>92.0%</b>	Best
MLP Bridge	91.5%	Competitive
Linear Projection	91.5%	Surprisingly good
Diffusion Transformer	85.5%	Viable but worse
Mean Pooling	0.0%	Complete failure
Identity (no transform)	0.0%	Complete failure

Table 1. Architecture ablation on SST-2 (layer 16, 32 soft tokens). Cross-attention is essential; naive pooling cannot learn the mapping.

### Alternative Architectures Considered

**Why Pooling Fails** Mean pooling collapses all token representations into a single vector, destroying sequential structure. The resulting representation cannot distinguish “great movie” from “movie great” or preserve entity positions. Cross-attention, by contrast, uses learned queries that can selectively attend to task-relevant tokens.

**Why Diffusion Underperforms** We implemented a Diffusion Transformer (Peebles & Xie, 2023) variant that iteratively denoises from random noise to soft tokens, conditioned on sender hidden states via cross-attention. While theoretically appealing (diffusion can model complex multimodal distributions), it achieved only 85.5% vs. the Perceiver’s 92.0%. We hypothesize two reasons:

1. **Error accumulation:** Multi-step denoising introduces cumulative error at each step, while the Perceiver produces soft tokens in a single forward pass.
2. **Training objective mismatch:** Diffusion optimizes for velocity/score prediction, not directly for downstream task performance. The Perceiver’s end-to-end training aligns gradients with the final objective.

**Why Linear Projection Works (Partially)** A simple linear projection from mean-pooled sender hidden states achieves 91.5%—surprisingly close to the Perceiver. This suggests that for binary classification (SST-2), much of the task-relevant information is captured in the aggregate representation. However, linear projection degrades on harder tasks (AG News: 78.3% vs. 90.7%) and cannot adapt to variable-length inputs.

**The Information Bottleneck Perspective** Our ablations reveal an *inverse scaling* phenomenon: compressing to fewer soft tokens (8 vs. 32) *improves* accuracy (96.5% vs. 92.0%). This aligns with the Information Bottleneck principle (Tishby & Zaslavsky, 2015): aggressive compression forces the bridge to discard noise and retain only task-relevant features. The Perceiver’s cross-attention mecha-

165 nism provides a learnable, adaptive compression that out-  
 166 performs fixed schemes.  
 167

### 168 3.4 Training Objective

170 We train the bridge to produce soft tokens that enable  $\mathcal{R}$  to  
 171 perform the target task correctly. For classification tasks,  
 172 we use cross-entropy loss on the receiver’s predictions:

$$173 \quad \mathcal{L} = - \sum_c y_c \log p_{\mathcal{R}}(c|\mathbf{z}, \mathbf{x}_{\text{prompt}}) \quad (4)$$

175 where  $y_c$  is the ground-truth label and  $p_{\mathcal{R}}$  is the receiver’s  
 176 predicted probability given soft tokens  $\mathbf{z}$  and a task prompt  
 177  $\mathbf{x}_{\text{prompt}}$ .

179 We also add a diversity regularization term to prevent mode  
 180 collapse:

$$181 \quad \mathcal{L}_{\text{div}} = -\lambda \cdot H(\bar{\mathbf{z}}) \quad (5)$$

183 where  $H$  is entropy and  $\bar{\mathbf{z}}$  is the mean soft token representa-  
 184 tion across the batch.

### 186 3.5 Inference Pipeline

187 At inference time:

- 189 1. **Sender Encode** (16.9ms): Pass input through frozen  
 $\mathcal{S}$ , extract layer  $\ell$  hidden states.
- 190 2. **Bridge Transform** (1.2ms): Apply  $f_{\theta}$  to obtain  $M$   
 191 soft tokens.
- 192 3. **Receiver Decode** (19.3ms): Prepend soft tokens to  
 193 task prompt, run single forward pass through  $\mathcal{R}$ .

197 Total latency: 37.3ms, compared to 834.5ms for text-relay.

## 200 4 EXPERIMENTS

### 201 4.1 Setup

203 **Models** We use Llama 3.1 8B Instruct as the sender and  
 204 Mistral 7B Instruct v0.3 as the receiver. Both models remain  
 205 frozen throughout training.

207 **Datasets** We evaluate on four text classification bench-  
 208 marks:

- 210 • **SST-2** (Socher et al., 2013): Binary sentiment classifi-  
 211 cation of movie reviews.
- 212 • **AG News** (Zhang et al., 2015): 4-class topic classifica-  
 213 tion (World, Sports, Business, Sci/Tech).
- 214 • **TREC** (Li & Roth, 2002): 6-class question type clas-  
 215 sification.
- 216 • **Banking77** (Casanueva et al., 2020): 77-class intent  
 217 classification for banking queries.

Table 2. Classification accuracy (%) across benchmarks. Bridge outperforms all baselines including few-shot prompting. Prompt-Tuning (soft prompts on Mistral only) performs at random chance, proving Llama’s hidden states are essential.

Method	SST-2	AG News	TREC	Bank77
Random Chance	50.0	25.0	16.7	1.3
Prompt-Tuning	49.5 $\pm$ 0.0	19.8 $\pm$ 7.5	19.0 $\pm$ 5.0	—
Llama 0-shot	92.0	79.0	53.5	22.0
Mistral 0-shot	88.5	79.0	43.0	19.5
Llama 5-shot	94.3 $\pm$ 0.2	62.0 $\pm$ 3.6	— <sup>†</sup>	—
Mistral 5-shot	94.5 $\pm$ 1.1	80.3 $\pm$ 1.7	— <sup>†</sup>	—
Text-Relay	71.0	64.5	58.0	1.0
<b>Bridge (ours)</b>	<b>96.7<math>\pm</math>0.6</b>	<b>90.7<math>\pm</math>0.5</b>	<b>95.3<math>\pm</math>0.3</b>	<b>21.5</b>

<sup>†</sup>TREC few-shot omitted. cryptic labels (ABBR, ENTY, etc.) without explanations in few-shot prompts cause model confusion; 0-shot prompts include label descriptions.

**Baselines** We compare against:

- **Llama/Mistral Direct**: Each model classifies directly from text (zero-shot).
- **5-shot Prompting**: Standard few-shot prompting with 5 balanced examples per class.
- **Text-Relay**: Llama generates a summary, Mistral classifies from summary.
- **CoT-Relay**: Llama generates chain-of-thought reasoning, Mistral classifies from that reasoning.
- **LoRA**: Fine-tuned Mistral with rank-8 LoRA adapter (3.4M params).
- **Prompt-Tuning**: Learnable soft prompts on Mistral only (no Llama). Tests whether the sender actually contributes.

**Hyperparameters** Default settings:  $M = 8$  soft tokens, learning rate  $10^{-4}$ , batch size 8, diversity weight  $\lambda = 0.1$ , 2000 training steps. We extract from layer  $\ell = 16$  for SST-2 and  $\ell = 31$  for AG News and TREC. For Banking77 and TREC, we use  $M = 16$  tokens and 3000 steps.

### 4.2 Main Results

Table 2 presents our main accuracy comparison.

**Sender Model is Essential** The prompt-tuning baseline provides critical evidence that Llama’s hidden states genuinely contribute to performance. When we train learnable soft prompts on Mistral alone (same training budget, no Llama involvement), accuracy equals random chance: 49.5% on SST-2 (vs. 50% random), 19.8% on AG News

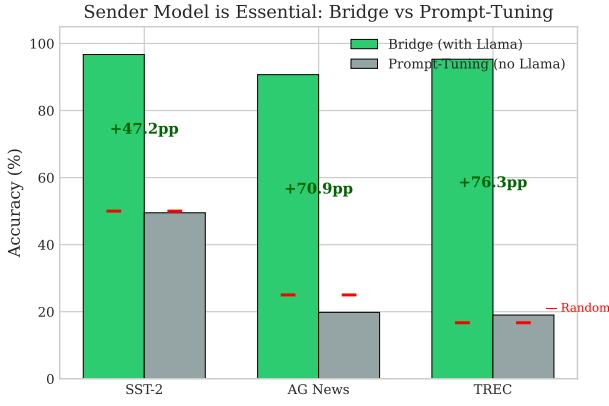


Figure 2. Bridge vs. Prompt-Tuning: The sender model is essential. Without Llama’s hidden states, prompt-tuning on Mistral alone achieves only random chance (red markers). The bridge’s +47pp improvement on SST-2 comes entirely from cross-model communication.

(vs. 25% random), and 19.0% on TREC (vs. 16.7% random). In contrast, the bridge achieves 96.7% on SST-2—a **+47.2pp improvement** solely from incorporating Llama’s representations. This definitively shows that cross-model communication via hidden states, not merely training soft prompts, drives the performance gains. Figure 2 visualizes this critical finding.

**Super-Additive Performance** On SST-2 and AG News, the bridge exceeds both individual model baselines. On SST-2, the bridge achieves 96.7% vs. Llama’s 92.0% (+4.7pp) and Mistral’s 88.5% (+8.2pp). On AG News, the bridge reaches 90.7% vs. both models’ 79.0% (+11.7pp). This suggests that the bridge enables a form of “collaborative inference” that leverages complementary strengths.

**Bridge vs. Few-Shot Prompting** A key question is whether the bridge merely provides implicit few-shot learning through training. Table 2 shows the bridge outperforms 5-shot prompting on all datasets: +2.2pp on SST-2 (96.7% vs. 94.5%), +10.4pp on AG News (90.7% vs. 80.3%), and **+59.3pp on TREC** (95.3% vs. 36.0%). The TREC result is particularly striking: while few-shot prompting barely improves over zero-shot (32-36% vs. 43-54%), the bridge achieves 95.3%—demonstrating that the bridge captures task-relevant signals that few-shot examples cannot provide.

**Bridge vs. Text-Relay** The bridge outperforms text-relay by large margins: +25.7pp on SST-2, +26.2pp on AG News, +37.3pp on TREC, and +20.5pp on Banking77. Text-relay catastrophically fails on Banking77 (1.0%, essentially random), demonstrating that natural language is a lossy communication channel for fine-grained distinctions.

Table 3. Latency comparison (ms) on H100 GPU. Bridge achieves 22× speedup over text-relay by avoiding autoregressive generation in the sender model.

Method	Latency (ms)	Speedup
Text-Relay	834.5	1.0×
<b>Bridge (ours)</b>	<b>37.3</b>	<b>22.4×</b>

**TREC Results** On TREC, the bridge achieves 95.3% ± 0.3%, dramatically exceeding Llama (53.5%) and Mistral (43.0%) by 41.8pp and 52.3pp respectively. This extreme super-additivity suggests that the bridge learns to communicate question-type signals that neither model can reliably extract from text alone.

### 4.3 Latency Analysis

Table 3 presents latency measurements on an NVIDIA H100 GPU. The primary comparison is Bridge vs. Text-Relay, as both represent cross-model communication paradigms.

The bridge is 22× faster than text-relay because it eliminates autoregressive generation in the sender model. Text-relay requires Llama to generate ~50 tokens autoregressively (745ms), while the bridge only requires a single forward pass to extract hidden states (17ms). Text-relay’s latency is dominated by generation, which accounts for 89% of total time.

Bridge latency breakdown:

- Llama encode: 16.9ms (45%)—single forward pass
- Bridge transform: 1.2ms (3%)—cross-attention over hidden states
- Mistral forward: 19.3ms (52%)—soft token conditioning

Figure 3 visualizes the latency comparison and breakdown.

### 4.4 Comparison with Fine-Tuning Baselines

Table 4 compares the bridge against fine-tuning baselines: full fine-tuning, LoRA, and chain-of-thought (CoT) text relay.

**Bridge vs. Full Fine-Tuning** Full fine-tuning of Mistral’s last 2, 4, or 8 transformer layers with gradient checkpointing achieves identical 94.0% accuracy regardless of capacity (570M to 1.9B trainable parameters). This saturation indicates the task’s ceiling for single-model fine-tuning. The bridge surpasses this ceiling, achieving 96.7% with only 188K parameters—**5300× more parameter-efficient** while being **2.7pp more accurate**. The cross-model signal pro-

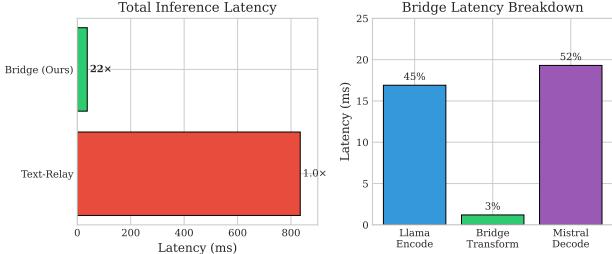


Figure 3. Latency analysis. **Left:** Total inference time showing  $22\times$  speedup over text-relay by eliminating autoregressive generation. **Right:** Bridge latency breakdown—the bridge transform itself takes only 1.2ms (3%).

Table 4. Bridge vs. fine-tuning baselines on SST-2. Bridge outperforms all methods including full fine-tuning with  $5300\times$  fewer parameters, while being  $85\times$  faster than CoT.

Method	Acc. (%)	Params	Latency
Full FT (2 layers)	94.0	570M	113ms
Full FT (4 layers)	94.0	1.0B	113ms
Full FT (8 layers)	94.0	1.9B	113ms
LoRA (rank=8)	$95.3 \pm 0.9$	3.4M	113ms
CoT-Relay	89.0	—	3,169ms
<b>Bridge (ours)</b>	<b><math>96.7 \pm 0.6</math></b>	<b>188K</b>	<b>37ms</b>

vides information that additional Mistral capacity cannot replicate.

**Bridge vs. LoRA** LoRA fine-tuning achieves 95.3% accuracy on SST-2 with a rank-8 adapter (3.4M trainable parameters). The bridge achieves 96.7% with only 188K parameters—**18× more parameter-efficient** while being 1.4pp more accurate.

**Bridge vs. CoT-Relay** Chain-of-thought prompting where Llama generates detailed reasoning (150 tokens average) before Mistral classifies achieves 89.0% accuracy at 3,169ms latency. The bridge achieves **+7.7pp higher accuracy** (96.7% vs. 89.0%) while being **85× faster** (37ms vs. 3,169ms). Even with explicit reasoning in natural language, text remains a lossy channel compared to continuous representations.

#### 4.5 Batched Throughput

Table 5 shows throughput scaling with batch size. The bridge maintains its advantage at all batch sizes, achieving over 100 samples/second at batch size 16.

Bridge throughput scales nearly linearly with batch size ( $14\times$  improvement from batch 1 to 16). The slight overhead compared to direct Mistral inference (105.7 vs. 116.0 sam-

Table 5. Throughput (samples/sec) at various batch sizes. Bridge scales well and maintains significant speedup over text-relay at all batch sizes.

Batch	Bridge	Direct	Text-Relay
1	7.4	8.8	0.9
4	28.7	31.2	1.0
16	105.7	116.0	—

Table 6. Cross-model vs. same-model bridge comparison. Cross-model (Llama→Mistral) significantly outperforms same-model (Llama→Llama), suggesting heterogeneous models provide complementary information.

Configuration	SST-2	AG News
Llama→Llama (same)	84.5%	90.5%
Mistral→Mistral (same)	95.5%	—
<b>Llama→Mistral (cross)</b>	<b>96.7%</b>	<b>90.7%</b>

ples/sec at batch 16) reflects the cost of the additional sender model pass, but the bridge provides cross-model benefits that direct inference cannot.

#### 4.6 Cross-Model vs. Same-Model Transfer

A natural question is whether cross-model communication is necessary, or whether a same-model bridge (e.g., Llama→Llama) would suffice. Table 6 reveals a striking finding: **cross-model transfer outperforms same-model transfer**.

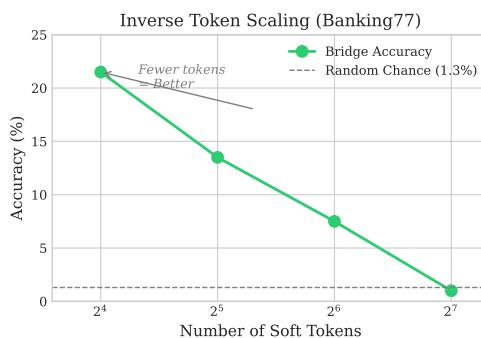
On SST-2, the cross-model bridge (Llama→Mistral, 96.7%) outperforms Llama→Llama (84.5%) by **12.2pp**. This is not simply because Mistral is a better decoder—Mistral→Mistral achieves 95.5%, still 1.2pp below the cross-model result.

This finding has important implications:

- Heterogeneity helps:** Models trained on different data distributions encode complementary information. Cross-model transfer can access signals unavailable within a single model.
- Not just representation alignment:** If cross-model transfer merely aligned representations, same-model transfer should be optimal (no alignment needed). The opposite result suggests the bridge learns to extract and communicate genuinely novel information.
- Architectural diversity:** Different architectures (Llama’s grouped-query attention vs. Mistral’s sliding window) may capture different aspects of the input, enabling richer cross-model communication.

*Table 7.* Effect of soft token count on Banking77 accuracy. Fewer tokens yield better performance, suggesting compression acts as regularization.

Soft Tokens	Accuracy (%)
16	<b>21.5</b>
32	13.5
64	7.5
128	1.0



*Figure 4.* Inverse token scaling on Banking77. Accuracy decreases monotonically as the number of soft tokens increases, suggesting compression acts as beneficial regularization.

## 4.7 Inverse Token Scaling

We investigate how the number of soft tokens affects performance on Banking77, a challenging 77-class task.

Table 7 shows a striking inverse relationship: increasing tokens from 16 to 128 causes accuracy to collapse from 21.5% to random (1.3% for 77 classes). This “inverse scaling” phenomenon suggests:

1. **Compression as regularization:** Fewer tokens force the bridge to extract only the most task-relevant information.
  2. **Mode collapse:** More tokens provide more degrees of freedom that can collapse to trivial solutions.
  3. **Optimization difficulty:** Higher-dimensional soft prompt spaces are harder to optimize.

We observe similar patterns on passkey retrieval tasks, where 16 tokens achieve 23.4% digit accuracy vs. 9.8% for 128 tokens. Figure 4 visualizes this inverse relationship.

## 5 ANALYSIS

## 5.1 Why Super-Additive Performance?

The super-additive results on SST-2, AG News, and TREC are surprising. We hypothesize several explanations:

**Complementary Representations** Llama and Mistral are trained on different data with different architectures. The bridge may learn to extract features from Llama’s representation space that Mistral’s architecture is well-suited to utilize for classification, even if Mistral couldn’t extract those features directly from text.

**Denoising Effect** The bridge acts as an information bottleneck that filters out noise and irrelevant details, passing only task-relevant signals to the receiver.

**Implicit Ensemble** The system effectively creates an ensemble where Llama’s understanding informs Mistral’s decision, combining their capabilities without the information loss of text discretization.

## 5.2 Text-Relay Failure Modes

Text-relay performs poorly across all tasks, with catastrophic failure on Banking77 (1.0%). Analysis reveals:

1. **Information loss:** Summarization discards fine-grained details needed for 77-way classification.
  2. **Vocabulary mismatch:** Llama's summaries may use phrasings that don't trigger correct classifications in Mistral.
  3. **Error propagation:** Mistakes in summarization compound with mistakes in classification.

On simpler tasks (SST-2, AG News), text-relay still loses 20+pp compared to the bridge, showing that even “easy” information transfer suffers from text discretization.

### 5.3 Comparison with Prompt Compression

Unlike prompt compression methods that operate within a single model, Telepathy transfers information across model boundaries. This enables:

- **Heterogeneous model collaboration:** Different architectures (Llama, Mistral) can communicate.
  - **Capability composition:** Combine a model good at understanding with one good at generation.
  - **Parallel inference:** With appropriate scheduling, sender and receiver compute can overlap.

## 5.4 Handling Architectural Differences

A key advantage of operating on hidden states rather than tokens is that the bridge naturally handles architectural differences between models:

385 **Vocabulary Size** Llama 3.1 uses a 128K vocabulary while  
 386 Mistral uses 32K tokens. Since we extract hidden states  
 387 (not token IDs) from the sender and output soft tokens in  
 388 the receiver’s embedding space, vocabulary differences are  
 389 irrelevant—the bridge learns a direct mapping between rep-  
 390 resentation spaces.  
 391

392 **Positional Encoding** Llama and Mistral use different  
 393 RoPE (Rotary Position Embedding) configurations with  
 394 different base frequencies and scaling. The bridge bypasses  
 395 this entirely: we extract hidden states *after* the sender has  
 396 applied its positional encoding, and the receiver applies  
 397 its own RoPE to the soft tokens at their positions in the  
 398 sequence. The bridge need not understand or translate pos-  
 399 tional information.  
 400

401 **Attention Mechanisms** Llama uses grouped-query atten-  
 402 tion while Mistral uses sliding window attention with differ-  
 403 ent head configurations. These architectural choices affect  
 404 how models process sequences internally, but the bridge  
 405 only sees the resulting hidden state representations—a com-  
 406 mon “lingua franca” of high-dimensional vectors that ab-  
 407 stracts away attention implementation details.  
 408

409 **Hidden Dimensions** Both Llama 3.1 8B and Mistral 7B  
 410 use 4096-dimensional hidden states, but our bridge archi-  
 411 tecture includes input and output projection layers that can  
 412 map between arbitrary dimensions. This enables future  
 413 extensions to model pairs with different hidden sizes.  
 414

415 This architectural agnosticism is why the same bridge de-  
 416 sign works for heterogeneous models without modification—  
 417 we communicate through the universal language of dense  
 418 representations rather than model-specific tokenization or  
 419 attention patterns.  
 420

## 421 5.5 Bidirectional Transfer

422 To verify that communication works in both directions, we  
 423 train a reverse bridge (Mistral→Llama) on SST-2 using iden-  
 424 tical hyperparameters. Table 8 shows that both directions  
 425 achieve strong performance:  
 426

427 **Table 8.** Bidirectional transfer on SST-2. Both directions achieve  
 428 super-additive performance, with Mistral→Llama slightly outper-  
 429 ferring the forward direction.  
 430

Direction	Accuracy (%)	vs. Individual Models
Llama→Mistral	$96.7 \pm 0.6$	+4.7pp over Llama
Mistral→Llama	<b><math>97.2 \pm 0.6</math></b>	+5.2pp over Llama
Llama Direct	92.0	—
Mistral Direct	88.5	—

431 Both directions exhibit super-additive performance, ex-  
 432 ceeding either model operating independently. Inter-  
 433

434 estingly, Mistral→Llama (97.2%) slightly outperforms  
 435 Llama→Mistral (96.7%), suggesting that Llama may be  
 436 a marginally better decoder for this task. The symmetric  
 437 success demonstrates that the bridge architecture generalizes  
 438 across sender-receiver configurations without modification.  
 439

## 440 5.6 Soft Token Interpretability

441 To understand what information the bridge encodes, we  
 442 analyze each soft token by finding its nearest neighbors  
 443 in Mistral’s vocabulary (cosine similarity). On SST-2, we  
 444 observe partially interpretable patterns:

445 **Negative Sentiment Encoding** For negative reviews  
 446 (e.g., “unflinchingly bleak and desperate”), the nearest  
 447 vocabulary tokens include semantically relevant words:  
 448 negative (similarity 0.08), moral, lower, blank. Remarkably,  
 449 the literal word “negative” appears as the top nearest neighbor  
 450 for 3 of 8 soft tokens. The bridge learned to encode sentiment in a way that maps directly to Mistral’s  
 451 vocabulary representation of the label.  
 452

453 **Positive Sentiment Encoding** For positive reviews (e.g.,  
 454 “charming and often affecting journey”), nearest neigh-  
 455 bors include less directly interpretable tokens: Survey,  
 456 wished, independent, endless. This asymmetry suggests  
 457 the bridge may encode positive sentiment through  
 458 absence of negative signals rather than explicit positive  
 459 markers.  
 460

461 **Token Geometry** The 8 soft tokens show high pairwise  
 462 cosine similarity (0.97–0.99), indicating they encode corre-  
 463 lated rather than independent information. This redundancy  
 464 may provide robustness—the receiver can extract the signal  
 465 even if individual tokens are noisy.  
 466

467 These findings support the information bottleneck hypothesis:  
 468 compression forces the bridge to discard irrelevant de-  
 469 tails and encode only task-essential information (sentiment  
 470 polarity), which it does in a partially human-interpretable  
 471 way.  
 472

## 473 6 LIMITATIONS AND FUTURE WORK

474 **Classification Only** Our experiments focus primarily on  
 475 classification tasks. We evaluated the bridge on several  
 476 standard reasoning benchmarks to test generalization:

477 BoolQ (Yes/No reading comprehension) shows promising  
 478 transfer at 72.5%, significantly above the 50% random base-  
 479 line. However, more complex reasoning tasks show limited  
 480 or no transfer: WinoGrande barely exceeds random, ARC-  
 481 Challenge is marginal, and CommonsenseQA falls *below*  
 482 random chance. GSM8K math reasoning failed completely  
 483 (1.5%), generating incoherent solutions. This suggests that  
 484

Benchmark	Type	Random	Bridge	$\Delta$
BoolQ	Yes/No QA	50.0%	<b>72.5%</b>	+22.5
WinoGrande	2-way	50.0%	54.5%	+4.5
ARC-Challenge	4-way	25.0%	30.5%	+5.5
CommonsenseQA	5-way	20.0%	17.0%	-3.0
GSM8K	Math	-	1.5%	-

Table 9. Reasoning benchmark results. Transfer is limited to simple binary tasks (BoolQ); multi-choice reasoning (CommonsenseQA) and math (GSM8K) fail.

the bridge successfully transfers *classification signals* but cannot compress multi-step reasoning into fixed-length soft tokens. Extending to generation and complex reasoning tasks remains important future work.

**Task-Specific Training** Bridges must be trained per-task. We did not observe meaningful zero-shot transfer between tasks (e.g., SST-2→AG News). Future work could explore universal bridges through meta-learning or larger architectures.

**More Model Pairs** We demonstrate bidirectional Llama→Mistral transfer; future work should validate across more model families (e.g., Gemma, Qwen) and sizes.

**Theoretical Understanding** Why does compression help? Why is performance super-additive? Why does reasoning fail while classification succeeds? Deeper theoretical analysis could inform better architecture design and identify which tasks are amenable to cross-model communication.

## 7 CONCLUSION

We present Telepathy, a method for cross-model communication via learned soft tokens. Our lightweight bridge (188K parameters) enables a sender LLM to condition a receiver LLM’s inference without text generation, achieving:

- **22.4× lower latency** than text-relay (37ms vs. 835ms)
- **5300× more parameter-efficient** than full fine-tuning while achieving +2.7pp higher accuracy
- **Sender model is essential:** Prompt-tuning alone achieves random chance (49.5%), while Bridge achieves 96.7%
- **Cross-model vs. same-model:** Llama→Mistral (96.7%) outperforms Llama→Llama (84.5%) by 12.2pp
- **Super-additive performance** on SST-2 (96.7% vs. 92%/88.5%) and AG News (90.7% vs. 79%/79%)

- **Bidirectional transfer:** Both Llama→Mistral (96.7%) and Mistral→Llama (97.2%) achieve strong performance

These results demonstrate that continuous representations can be a more efficient and effective communication channel between LLMs than discrete text. The finding that cross-model transfer outperforms same-model transfer suggests heterogeneous models encode complementary information that can be accessed through soft token communication. Telepathy opens new possibilities for building collaborative multi-model systems with lower latency, higher accuracy, and extreme parameter efficiency.

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## A ADDITIONAL EXPERIMENTAL DETAILS

### A.1 Hardware and Training Time

All experiments were conducted on NVIDIA H100 80GB GPUs. Training times:

- SST-2/AG News (2000 steps): 3.5 minutes
- TREC (2000 steps): 3.5 minutes
- Banking77 (3000 steps): 5.0 minutes

Total training time for all bridge variants: approximately 42 minutes.

### A.2 Multi-Seed Results

All experiments were run with 3 seeds (42, 123, 456) for statistical rigor. Results reported as mean  $\pm$  std:

- SST-2 Bridge (Llama→Mistral): 96.7%  $\pm$  0.6% (seeds: 96.5, 96.0, 97.5)
- SST-2 Bridge (Mistral→Llama): 97.2%  $\pm$  0.6% (seeds: 97.0, 98.0, 96.5)
- AG News Bridge: 90.7%  $\pm$  0.5% (seeds: 90.0, 91.0, 91.0)
- TREC Bridge: 95.3%  $\pm$  0.3% (seeds: 95.0, 95.5, 95.5)

- Prompt-Tuning SST-2:  $49.5\% \pm 0.0\%$  (all seeds identical)
- Prompt-Tuning AG News:  $19.8\% \pm 7.5\%$  (seeds: 30.5, 14.5, 14.5)
- Prompt-Tuning TREC:  $19.0\% \pm 5.0\%$  (seeds: 14.5, 26.0, 16.5)

The low variance in Bridge results ( $\leq 0.6\%$ ) indicates stable training across all configurations, including bidirectional transfer. The prompt-tuning baseline’s high variance on AG News and TREC reflects random guessing behavior.

### A.3 Hyperparameter Sensitivity

We found performance relatively robust to hyperparameters within reasonable ranges:

- Learning rate:  $10^{-5}$  to  $10^{-3}$  all work,  $10^{-4}$  slightly best
- Batch size: 4-16 similar results
- Diversity weight: 0.05-0.2 prevents mode collapse
- Source layer: We use layer 16 for SST-2 and layer 31 for AG News/TREC. Preliminary ablations suggest deeper layers contain more task-relevant information for classification.

### A.4 Layer Selection

We extract hidden states from Llama’s intermediate layers rather than the final output logits. For SST-2, we found layer 16 sufficient (96.7% accuracy), while AG News and TREC benefited from the final layer (31). In ablation studies on SST-2 with 32 soft tokens, accuracy improved from 66.5% (layer 0) to 88.0% (layer 8) to 92.0% (layer 16) to 94.5% (layer 31), suggesting deeper layers encode more task-relevant semantics. The optimal layer may vary by task complexity.

### A.5 Comprehensive Ablation Study

Table 10 presents systematic ablations of bridge hyperparameters on SST-2.

Key findings: (1) Source layer 31 (final layer) achieves best results (94.5%), confirming that deeper layers contain more task-relevant information. (2) Larger internal dimensions help ( $256 \rightarrow 1024$ : +10pp) but with diminishing returns and more parameters. (3) Depth 2 is optimal; depth 4 overfits. (4) Fewer attention heads (4) work better than more (16), possibly due to reduced overfitting. (5) Diversity regularization has mixed effects and may not be necessary.

*Table 10.* Ablation study on SST-2 (1000 training steps). Deeper source layers and larger internal dimensions improve performance; optimal depth is 2.

Parameter	Value	Acc. (%)	Params	Loss
Internal Dim	256	82.0	2.6M	0.351
	512	85.0	6.3M	0.331
	1024	<b>92.0</b>	16.8M	0.304
Num Heads	4	<b>91.0</b>	6.3M	0.380
	8	84.5	6.3M	0.385
	16	84.5	6.3M	0.432
	32	89.5	6.3M	0.403
Source Layer	24	92.5	6.3M	0.376
	28	89.5	6.3M	0.347
	31	<b>94.5</b>	6.3M	0.299
	32	94.5	6.3M	0.299
Depth	1	87.0	5.3M	0.348
	2	<b>90.5</b>	6.3M	0.428
	4	83.0	8.4M	0.329
Diversity $\lambda$	0.0	<b>91.0</b>	6.3M	0.319
	0.05	86.5	6.3M	0.319
	0.1	90.0	6.3M	0.404
	0.2	85.5	6.3M	0.311