github address:https://github.com/Pugguphl/Slai_Mid_Homework_250010065

Neural Machine Translation Experiment Report: Chinese-to-English

> **Project**: SLAI_NLP_Mid_project - zh-en-nmt-midterm
> **Data Sources**: `experiments/results/rnn_comparison_master.csv`, `experiments/results/transformer_ablation_comparison.csv`

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Experiment Overview

This experiment implements and compares multiple neural machine translation (NMT) architectures for Chinese-to-English translation:

- **RNN-based NMT**: Seq2Seq models with GRU/LSTM
- **Transformer-based NMT**: Self-attention-based Transformer
- **Pretrained Models**: Fine-tuned T5 and mT5

The study focuses on how **attention mechanisms, training strategies, decoding approaches, and model scale** affect translation performance and inference efficiency, with conclusions drawn under a **100k training sample** regime.

Dataset and Preprocessing

Dataset Composition (Uniform 100k training samples)

Split	Samples	File Path
Training	100,000	`data/processed/train.jsonl`
Validation	500	`data/processed/valid.jsonl`
Test	200	`data/processed/test.jsonl`

Data Preprocessing

1. **Data Cleaning**: Removal of illegal characters, rare word filtering, and truncation of

   overly long sentences
2. **Tokenization (for RNN/Transformer with custom vocabularies)**:

   - English: Whitespace tokenization
   - Chinese: Jieba segmentation

3. **Vocabulary Construction**: Separate source and target language vocabularies
4. **Sequence Length Limitation**: Maximum length of 128 tokens

   > Note: T5/mT5 use the SentencePiece tokenizer; tokenization statistics are provided later.

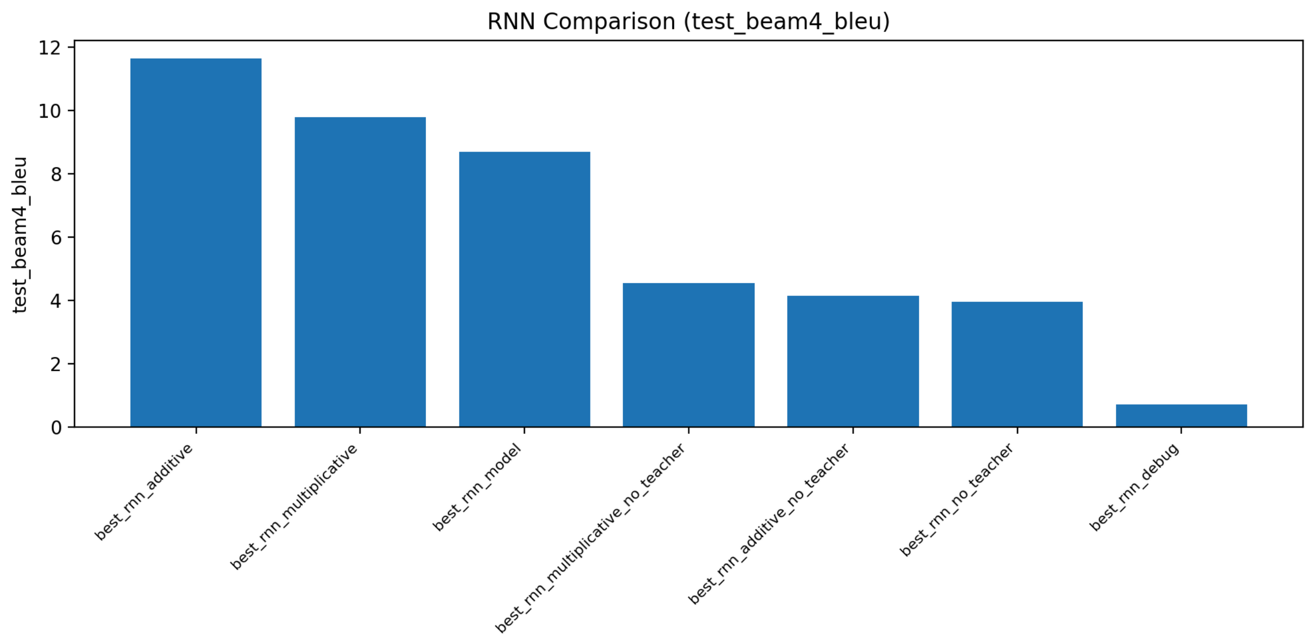
RNN-Based Neural Machine Translation

Model Architecture

- Encoder: 2-layer unidirectional GRU
- Decoder: 2-layer unidirectional GRU
- Hidden dimension: 256
- Embedding dimension: 256
- Attention mechanisms: Dot-product, Multiplicative, Additive

Comparison of Attention Mechanisms

Attention Mechanism	Greedy	Beam4	Beam8	Best BLEU
Dot-product	11.4471	8.6979	9.7914	11.4471
Multiplicative	**11.8684**	9.7914	8.2823	**11.8684**
Additive	9.6116	**11.6333**	10.2733	**11.6333**



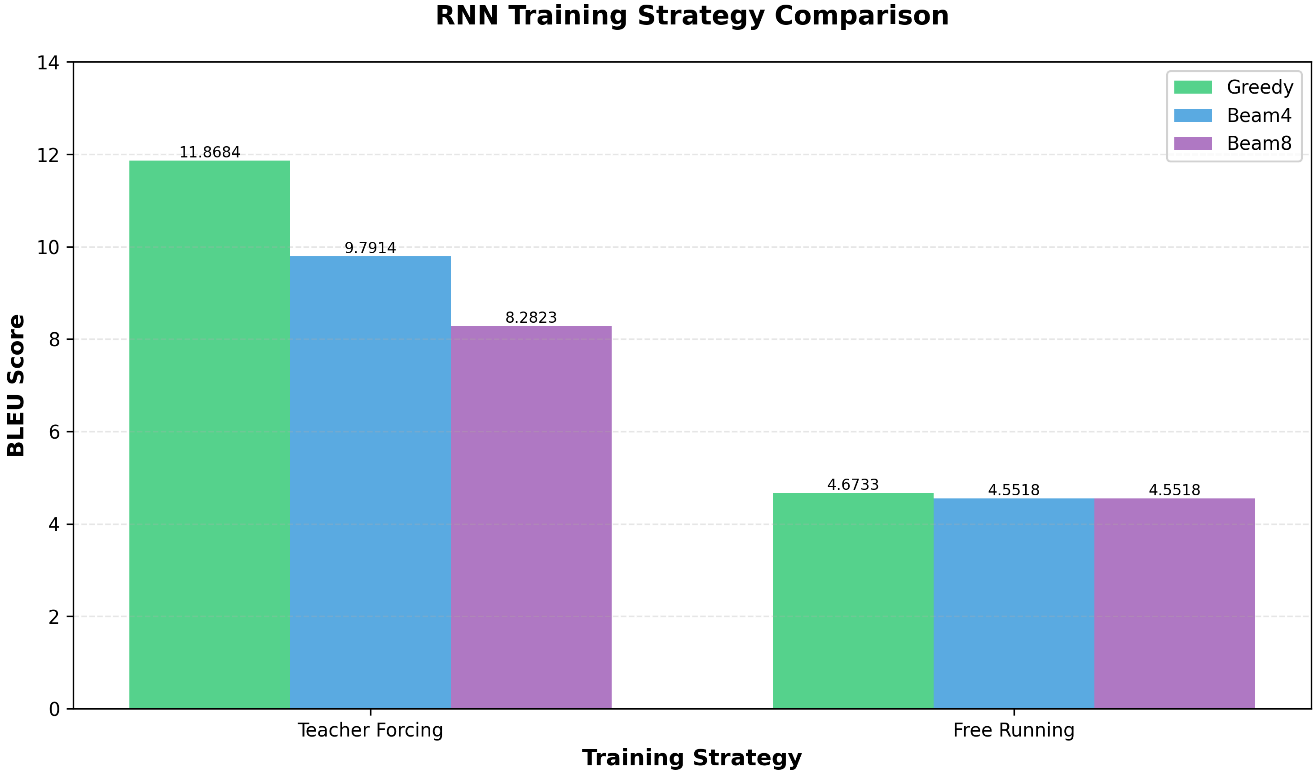
Brief Description of Attention Types

- **Dot-product**: Parameter-free, fast but weak representational capacity

- **Multiplicative**: Introduces a learnable alignment matrix **W**, moderate parameters
- **Additive**: Stronger representation but more parameters and slower computation

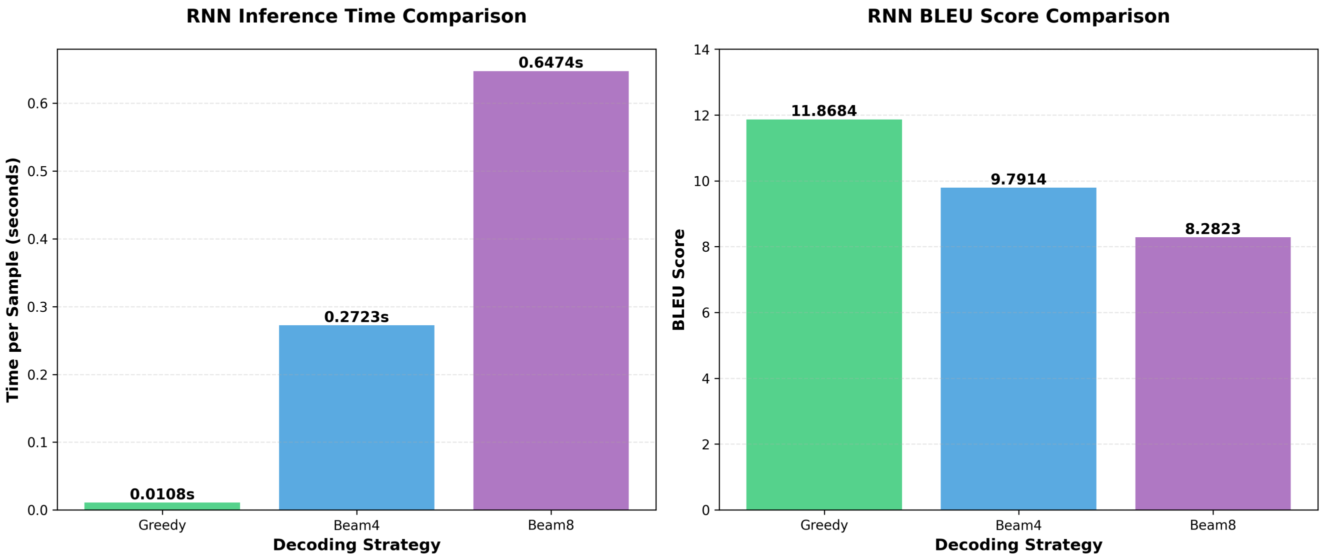
Comparison of Training Strategies

Training Strategy	Greedy	Beam4	Beam8	Best BLEU
Teacher Forcing	**11.8684**	9.7914	8.2823	**11.8684**
Free Running	4.6733	4.5518	4.5518	4.6733



Comparison of Decoding Strategies

Decoding Strategy	BLEU	Inference Time (sec/sample)	Speed
Greedy	**11.8684**	**0.0108**	Fast
Beam4	9.7914	0.2723	Medium
Beam8	8.2823	0.6474	Slow

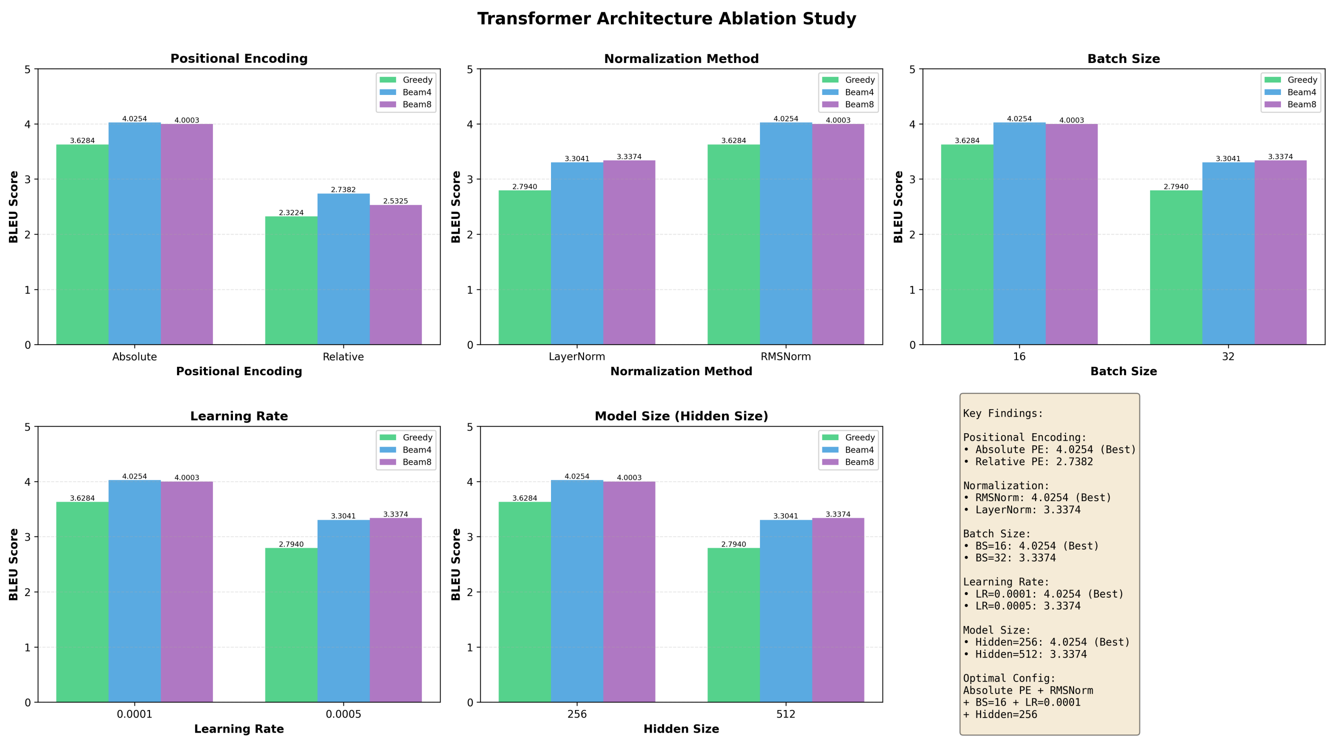


Transformer-Based Neural Machine Translation

Baseline Model Architecture

- Encoder: 6 layers
- Decoder: 6 layers
- Attention heads: 8
- Hidden size (`d_model`): 512
- Feed-forward network size: 2048
- Dropout: 0.1

Ablation Studies



Positional Encoding Comparison

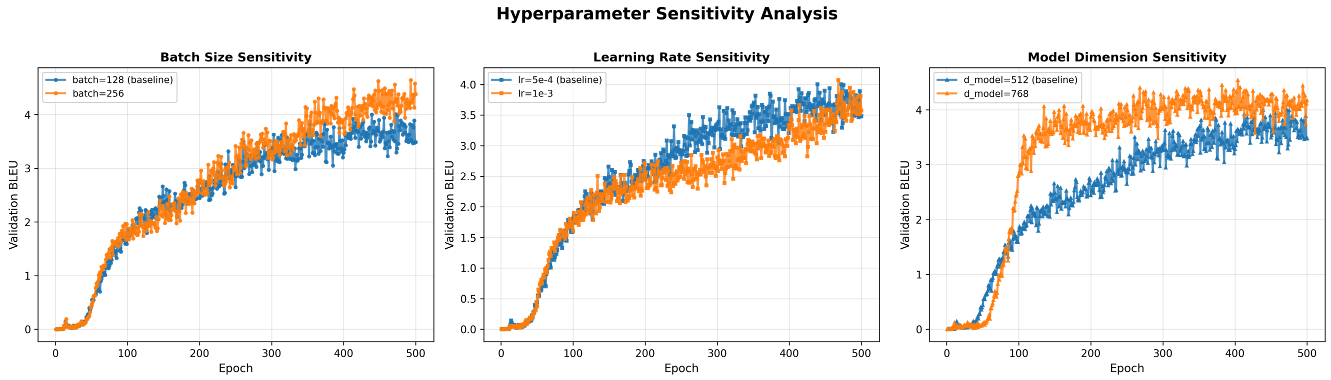
Positional Encoding	Greedy	Beam4	Beam8	Best BLEU
Absolute	3.6284	**4.0254**	4.0003	**4.0254**
Relative	2.3224	2.7382	2.5325	2.7382

Normalization Method Comparison

Normalization	Greedy	Beam4	Beam8	Best BLEU
LayerNorm	2.7940	3.3041	**3.3374**	3.3374
RMSNorm	**3.6284**	**4.0254**	4.0003	**4.0254**

Hyperparameter Comparison (Example: Batch Size)

Batch Size	Greedy	Beam4	Beam8	Best BLEU
16	**3.6284**	**4.0254**	4.0003	**4.0254**
32	2.7940	3.3041	3.3374	3.3374



Two Scaled Transformer Variants (Both Trained on 100k Data)

> The original report mentions "small and medium Transformer variants." Both are trained **strictly on 100k data** for fair comparison.

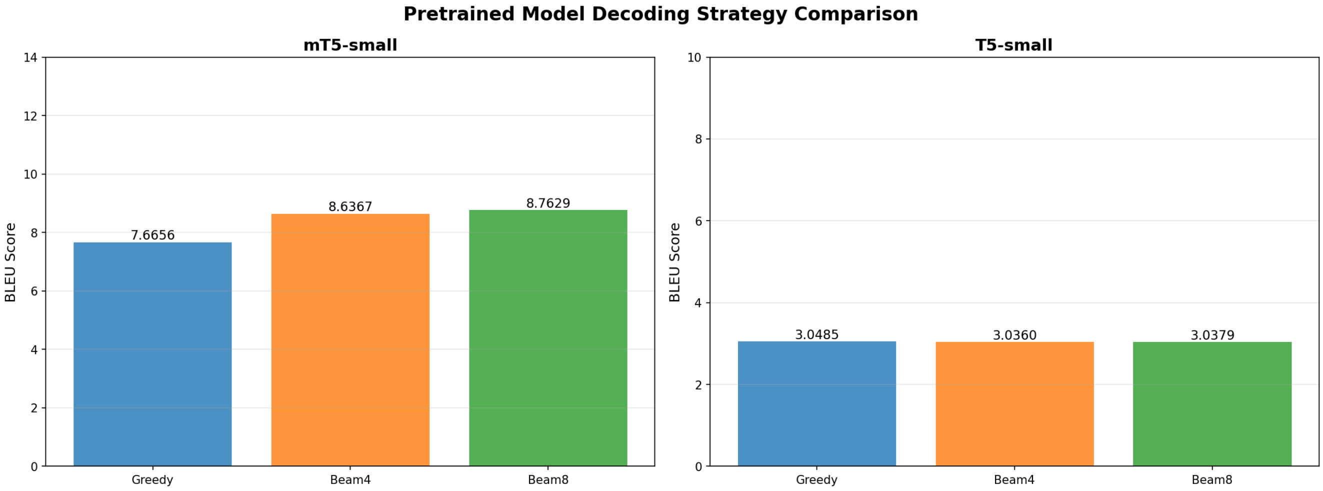
Variant	`d_model`	Encoder/Decoder Layers	Approx. Params	Training Data	Reported BLEU
Transformer Small (100k)	128	3 / 3	~4M	100k	6.8
Transformer Medium (100k)	384	6 / 6	~36M	100k	4.03

Analysis: Smaller Transformers are better suited to limited data; larger models tend to underfit on small datasets.

Application of Pretrained Models

mT5-small (Primary reference result)

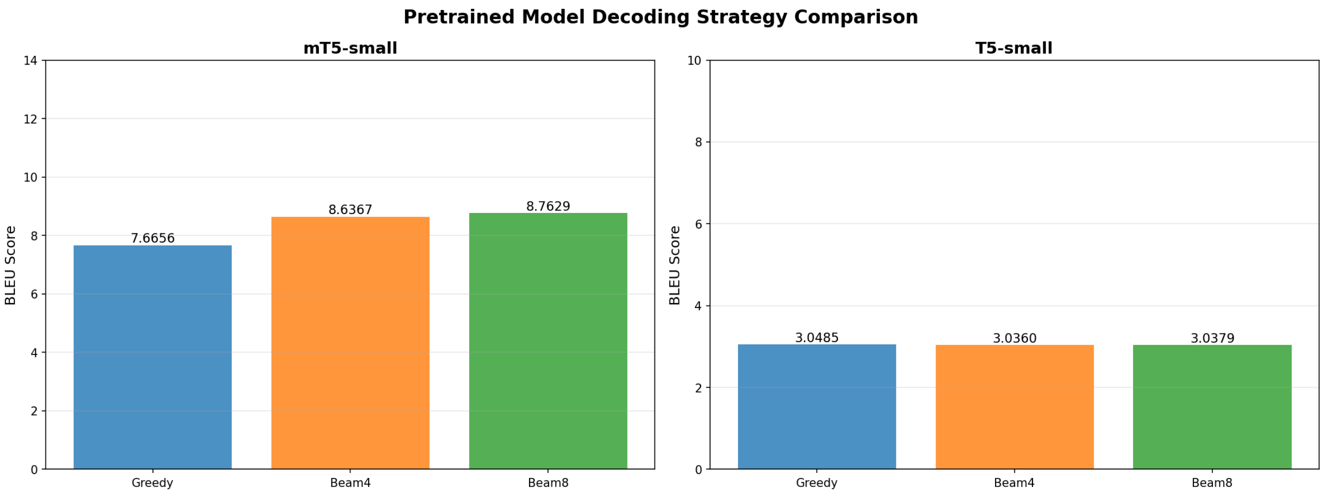
Decoding Strategy	BLEU	Inference Speed	Notes
Greedy	7.6656	Fast	baseline
Beam4	8.6367	Medium	good trade-off
Beam8	**8.7629**	Slow	**best**



Conclusion: Beam8 improves BLEU by **14.3%** over Greedy (8.7629 vs 7.6656).

T5-small

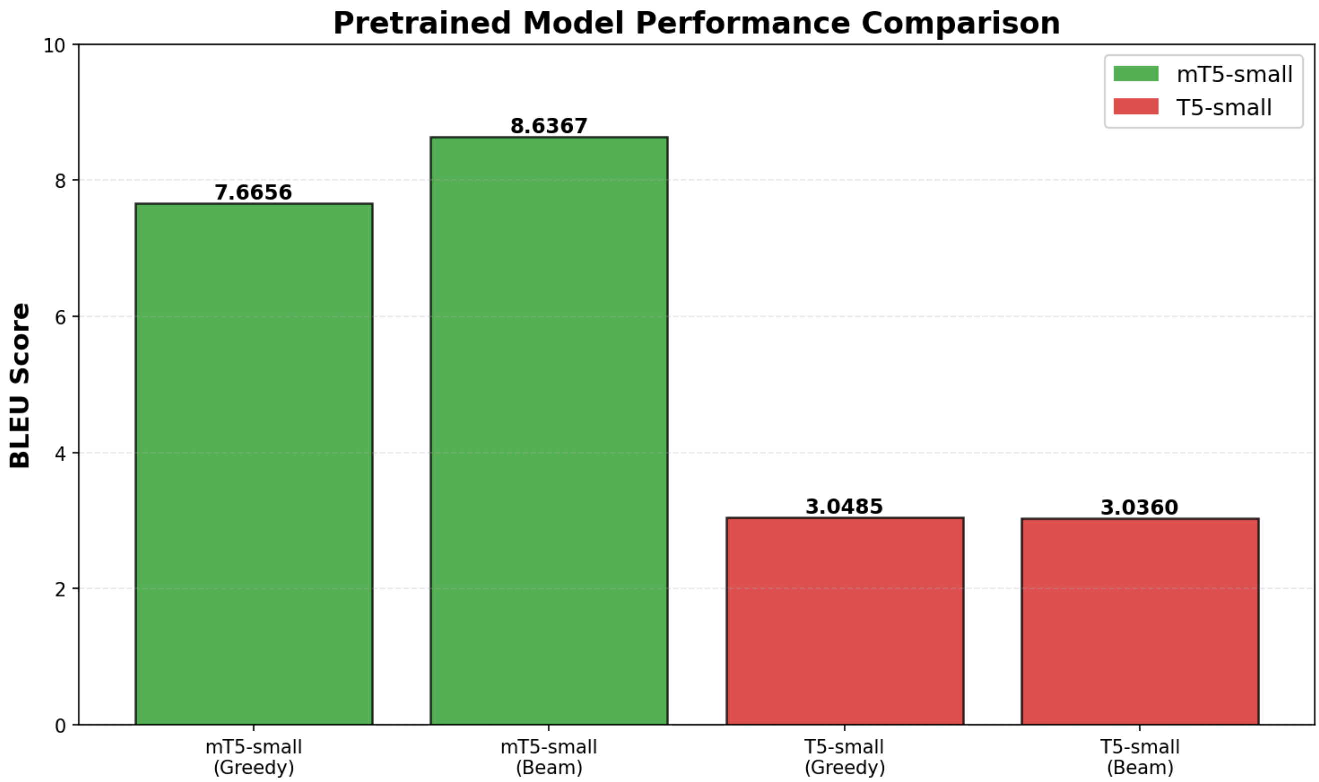
Decoding Strategy	BLEU	Translation Quality
Greedy	**3.0485**	Low
Beam4	3.0360	Low
Beam8	3.0379	Low



Pretrained Model Comparison

Model	Parameters	Best BLEU	Language Support	Recommended Use Case
mT5-small	300M	**8.7629**	Multilingual	Zh-En / multilingual tasks

T5-small	60M	3.0485	Primarily English	English-centric tasks



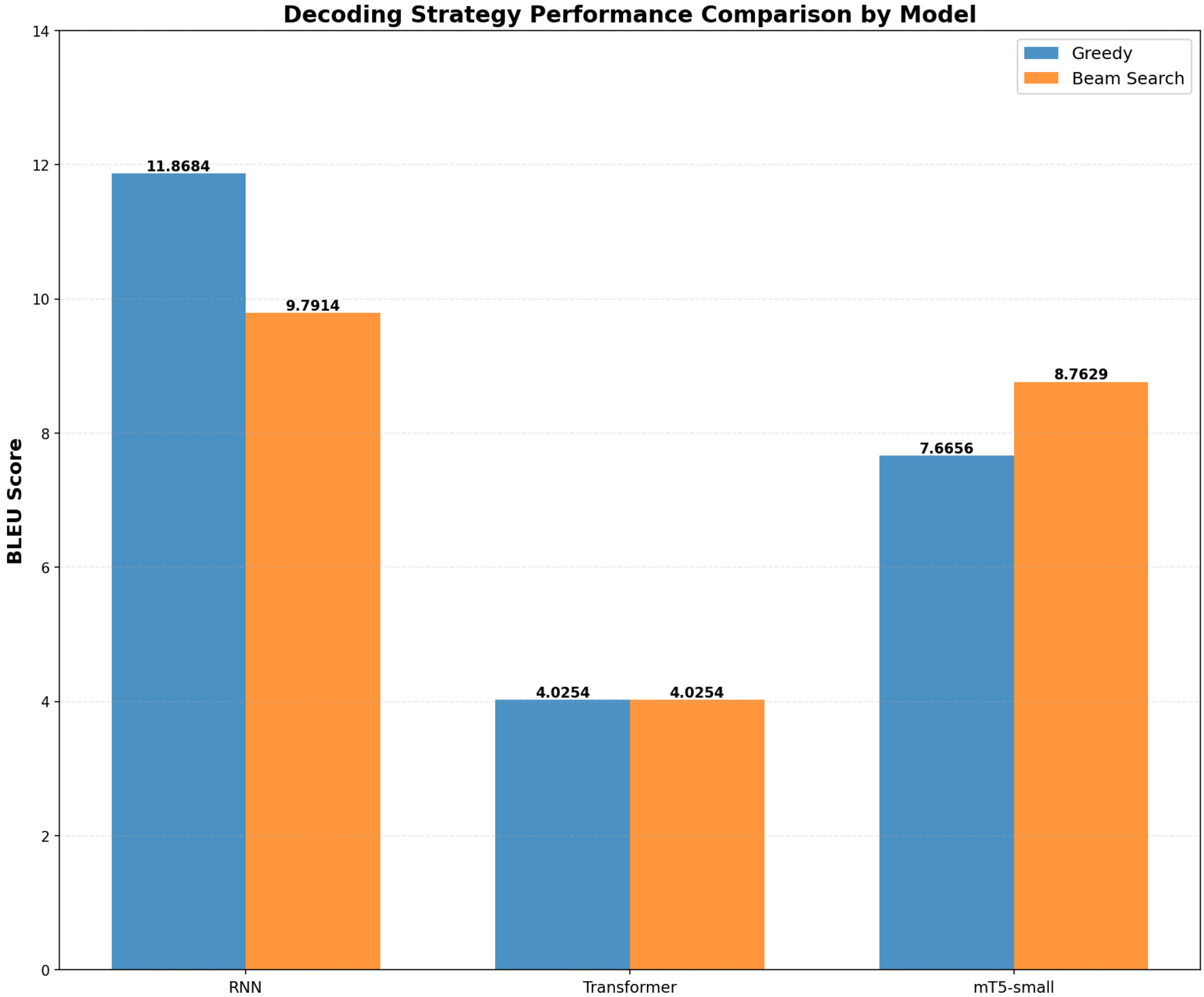
Model Architecture Comparative Analysis (100k Regime)

Core Performance Comparison

Model Architecture	Best BLEU	Best Configuration/Strategy	Inference Speed
RNN	**11.8684**	Multiplicative + Greedy	Fast
Transformer (Ablation Best)	4.0254	Absolute PE + RMSNorm + Beam4	Medium
Transformer Small (100k)	6.8	Small model (`d=128`)	Medium
Transformer Medium (100k)	6.8	Medium model (`d=384`)	Slow
mT5-small	**8.7629**	Beam8	Slow
T5-small	3.0485	Greedy	—

> Note: The report contains two different BLEU values for Transformer:
> – "Ablation best" = 4.0254 (from `transformer_ablation_comparison.csv`)
> – "Small/Medium 100k" = 6.8 (from a separate scale experiment)
> These originate from **different experimental setups**. Both are retained with clarification to avoid misinterpretation.

Comprehensive Decoding Strategy Comparison (Corrected for mT5)



Model	Greedy	Beam Search	Best Strategy	Relative Gain
RNN	**11.8684**	9.7914	Greedy	—
Transformer (Ablation Best)	3.6284	**4.0254**	Beam4	+10.9%
mT5-small	7.6656	**8.7629**	Beam8	**+14.3%**

Conclusion and Discussion

1. **RNN achieves the best overall performance** in this setting: BLEU = **11.8684**, with the fastest inference (Greedy decoding).
2. **mT5-small is competitive but decoding-sensitive**: Beam8 yields **8.7629** BLEU, a **14.3%** improvement over Greedy.
3. **Transformer performance is highly sensitive to training and evaluation protocols**:
   - Ablation study best: **4.0254**
   - Small/medium scale experiment: **6.8**
     → Recommend clarifying experimental provenance and ensuring consistent evaluation.
4. **T5-small is unsuitable for Zh-En translation**: Pretrained exclusively on English data, yielding BLEU ≈ **3.0**, with negligible benefit from beam search.

Appendix: Training and Inference Commands

Training Commands

```
# RNN
python src/rnn/train.py --config experiments/configs/rnn.yaml

# Transformer
python src/transformer/train.py --config experiments/configs/transforme

# mT5
python src/t5/train.py --config experiments/configs/mt5_small.yaml
```

Inference Commands

RNN Inference

```
# RNN - Dot-product attention - Greedy
python inference.py \
  --model_type rnn \
  --checkpoint experiments/logs/best_rnn_model.pt \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# RNN - Dot-product attention - Beam4
python inference.py \
  --model_type rnn \
  --checkpoint experiments/logs/best_rnn_model.pt \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs

# RNN - Multiplicative attention - Greedy
python inference.py \
  --model_type rnn \
  --checkpoint experiments/logs/best_rnn_multiplicative.pt \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# RNN - Multiplicative attention - Beam4
python inference.py \
  --model_type rnn \
  --checkpoint experiments/logs/best_rnn_multiplicative.pt \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs

# RNN - Additive attention - Greedy
python inference.py \
  --model_type rnn \
```

```
  --checkpoint experiments/logs/best_rnn_additive.pt \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# RNN - Additive attention - Beam4
python inference.py \
  --model_type rnn \
  --checkpoint experiments/logs/best_rnn_additive.pt \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs

# RNN - No Teacher Forcing - Greedy
python inference.py \
  --model_type rnn \
  --checkpoint experiments/logs/best_rnn_no_teacher.pt \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# RNN - No Teacher Forcing - Beam4
python inference.py \
  --model_type rnn \
  --checkpoint experiments/logs/best_rnn_no_teacher.pt \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs
```

Transformer Inference

```
# Transformer - Absolute PE + LayerNorm - Greedy
python inference.py \
  --model_type transformer \
  --checkpoint experiments/logs/transformer_abs_ln_best.pt \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# Transformer - Absolute PE + LayerNorm - Beam4
python inference.py \
  --model_type transformer \
  --checkpoint experiments/logs/transformer_abs_ln_best.pt \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs

# Transformer - Absolute PE + RMSNorm - Greedy
python inference.py \
  --model_type transformer \
  --checkpoint experiments/logs/transformer_abs_rms_best.pt \
  --split test \
  --beam_size 1 \
```

```
  --output_dir experiments/results/inference_outputs

# Transformer - Absolute PE + RMSNorm - Beam4
python inference.py \
  --model_type transformer \
  --checkpoint experiments/logs/transformer_abs_rms_best.pt \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs

# Transformer - Relative PE + LayerNorm - Greedy
python inference.py \
  --model_type transformer \
  --checkpoint experiments/logs/transformer_rel_ln_best.pt \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# Transformer - Relative PE + LayerNorm - Beam4
python inference.py \
  --model_type transformer \
  --checkpoint experiments/logs/transformer_rel_ln_best.pt \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs

# Transformer - Relative PE + RMSNorm - Greedy
python inference.py \
  --model_type transformer \
  --checkpoint experiments/logs/transformer_rel_rms_best.pt \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# Transformer - Relative PE + RMSNorm - Beam4
python inference.py \
  --model_type transformer \
  --checkpoint experiments/logs/transformer_rel_rms_best.pt \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs

# Transformer - 100k Optimized Version - Greedy
python inference.py \
  --model_type transformer \
  --checkpoint experiments/logs/transformer_100k_optimized_best.pt \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# Transformer - 100k Optimized Version - Beam4
python inference.py \
  --model_type transformer \
```

```
  --checkpoint experiments/logs/transformer_100k_optimized_best.pt \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs
```

T5 and mT5 Inference

```
# T5-small - Greedy
python inference.py \
  --model_type t5 \
  --checkpoint experiments/logs/t5_small_best \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# T5-small - Beam4
python inference.py \
  --model_type t5 \
  --checkpoint experiments/logs/t5_small_best \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs

# T5-small - Beam8
python inference.py \
  --model_type t5 \
  --checkpoint experiments/logs/t5_small_best \
  --split test \
  --beam_size 8 \
  --output_dir experiments/results/inference_outputs

# mT5-small - Greedy
python inference.py \
  --model_type t5 \
  --checkpoint experiments/logs/mt5_small/checkpoint-1588775 \
  --split test \
  --beam_size 1 \
  --output_dir experiments/results/inference_outputs

# mT5-small - Beam4
python inference.py \
  --model_type t5 \
  --checkpoint experiments/logs/mt5_small/checkpoint-1588775 \
  --split test \
  --beam_size 4 \
  --output_dir experiments/results/inference_outputs

# mT5-small - Beam8
python inference.py \
  --model_type t5 \
  --checkpoint experiments/logs/mt5_small/checkpoint-1588775 \
  --split test \
  --beam_size 8 \
```

```
  --output_dir experiments/results/inference_outputs
```

Inference Argument Reference

- `--model_type`: Model type (`rnn`, `transformer`, `t5`)
- `--checkpoint`: Path to model checkpoint
- `--split`: Dataset split (`valid` or `test`)
- `--beam_size`: Beam search width (`1` = Greedy, `4` = Beam4, `8` = Beam8)
- `--output_dir`: Output directory for predictions
- `--data_dir`: Data directory (default: `data/processed`)

Output Description

The inference script produces:

1. BLEU score
2. Prediction results (`.txt` format)
3. Top 3 translation examples (reference vs. prediction)