Hindi-Chhattisgarhi Cross-Lingual Transfer Using RL-Guided Distillation

Raghav Borikar : M24DS010 : raghavbori@iitbhilai.ac.in
Vikrant Sahu : P24CS007 : vikrantsahu@iitbhilai.ac.in

March 15, 2025

1 Project Overview

This roadmap is focused on next word prediction system, leveraging cross-lingual transfer learning between Hindi (high-resource) and Chhattisgarhi (low-resource). The project maintains the core reinforcement learning and knowledge distillation framework while redirecting goals toward language modeling capabilities.

2 Project Overview & Definition

This approach focuses on developing a specialized framework that efficiently transfers knowledge from Hindi language models to Chhattisgarhi for next word prediction tasks. This project will create predictive language models that can effectively complete sentences and predict subsequent words in Chhattisgarhi text by leveraging knowledge from pre-trained Hindi models. This approach addresses the "rich cousin, poor sister" relationship between the languages with applications in text completion, input suggestion systems, and predictive keyboards rather than translation.

The fundamental challenge is: how to effectively transfer linguistic knowledge from a high-resource language to a related low-resource language, & the task objective is predicting the next word in a sequence. This creates some technical challenges and opportunities for the reinforcement learning guidance system.

3 Project Structure

- Evaluation Metrics: perplexity and next-word prediction accuracy
- Model Architecture: autoregressive language models
- Reward Function: Optimizes for prediction accuracy rather than translation quality

4 Key Components

- **Pretrained Language Model Foundation:** Utilizing existing Hindi language models (such as HindiBERT, IndicBERT, or MuRIL) as the foundation.
- **Reinforcement Learning for Selective Knowledge Transfer:** Using RL to dynamically determine which components of the Hindi language model are most beneficial for Chhattisgarhi next word prediction.
- **Contextual Lexical Mapping** Leveraging Hindi-Chhattisgarhi lexical similarities to enhance context understanding for prediction tasks.
- **Knowledge Distillation for Prediction Models:** Implementing confidence-guided distillation techniques specifically tuned for next word prediction scenarios.

5 Project Timeline

5.1 Phase 1: Setup and Foundational Development

- **Environment Setup and Data Collection**
  - Configure development environment with required libraries and frameworks for language modeling tasks
  - Collect large monolingual Hindi corpora from public sources
  - Utilize the Hindi-Chhattisgarhi parallel corpus from NLLB dataset (40,000 sentences of Bible translations) as the foundation for cross-lingual transfer
  - Implement synthetic data generation techniques to expand the limited Chhattisgarhi resources:
    - Back-translation: Use initial Hindi→Chhattisgarhi model to generate additional Chhattisgarhi data from Hindi monolingual corpus
    - Quality filtering: Apply confidence-based filtering to ensure quality of synthetic data
    - Data augmentation: Implement contextual word replacement and synonym substitution to increase linguistic diversity beyond the Bible domain

    Create evaluation datasets from both in-domain (Bible) and out-of-domain texts to assess generalization capabilities
  - Develop or acquire additional Chhattisgarhi monolingual text for fine-tuning and evaluation
  - Set up evaluation metrics focused on perplexity, next-token accuracy, and contextual relevance
- **Base Model Architecture Design**
  - Select and implement appropriate language model architecture (e.g., transformer-based)
  - Create or adapt a Hindi-pretrained language model as the teacher model
  - Establish baseline language model performance metrics on Hindi
  - Develop data preprocessing pipelines optimized for next word prediction tasks in both languages
  - Implement tokenization strategies appropriate for morphologically rich languages
- **Knowledge Distillation Framework Implementation**
  - Develop teacher (Hindi) and student (Chhattisgarhi) model architectures for knowledge distillation
  - Implement confidence-guided distillation mechanisms based on DRL-Rec principles
  - Design prediction-level distillation using appropriate divergence metrics
  - Implement feature-level distillation to transfer intermediate representations

5.2 Phase 2: RL Framework Development

- **RL Environment Design**
  - Define state space (model parameters, prediction accuracy metrics, perplexity)
  - Define action space (parameter selection for transfer: freeze/fine-tune/replace)
  - Implement reward function based on next word prediction quality metrics
  - Create simulation environment for efficient RL training
- **Exploring and Filtering Module Implementation**
  - Develop exploring mechanism to identify valuable contextual patterns for transfer
  - Implement filtering strategies to select informative training instances

- Design confidence-guided filtering based on teacher model certainty for prediction tasks
- Create mechanisms to handle domain-specific vocabulary challenges

- **Policy Network Development and Integration**
  - Implement RL policy network using Proximal Policy Optimization (PPO)
  - Integrate policy network with the language model training framework
  - Establish monitoring metrics for RL agent performance
  - Develop mechanisms to balance exploration and exploitation during training

5.3 Phase 3: Training and Optimization

- **Initial Model Training**
  - Pre-train the base language model on Hindi corpus
  - Perform initial transfer learning experiments without RL guidance
  - Establish transfer learning baselines for comparison
  - Identify key challenges in direct knowledge transfer

- **Transfer Strategy Optimization**
  - Train the RL policy network to guide the knowledge transfer process
  - Optimize hyperparameters for both language modeling and RL components
  - Implement curriculum learning strategies if beneficial
  - Develop robust evaluation protocols for intermediate models

- **RL-Guided Distillation Process**
  - Execute full RL-guided distillation from Hindi to Chhattisgarhi language models
  - Perform ablation studies to identify critical components
  - Analyze the impact of different knowledge transfer strategies
  - Document successful and unsuccessful approaches

5.4 Phase 4: Evaluation and Documentation

- **Comprehensive Evaluation**
  - Evaluate next word prediction performance on Chhattisgarhi test sets
  - Compare with baselines and alternative approaches
  - Analyze model behavior across different linguistic contexts
  - Perform error analysis and identify areas for improvement

- **Documentation and Dissemination**
  - Draft research paper documenting methodology and results
  - Create comprehensive documentation for the codebase
  - Prepare demonstrations and visualization of model capabilities
  - Document limitations and future research directions

6 Project Repository Structure

```
rich-cousin-poor-sister/
|-- README.md
|-- LICENSE
|-- requirements.txt
|-- .gitignore
|-- data/
| |-- raw/
| |-- processed/
| |-- embeddings/
| |-- lexical_mappings/
| |-- evaluation/
|-- src/
| |-- models/
| |-- preprocessing/
| |-- training/
| |-- distillation/
| |-- reinforcement_learning/
| |-- evaluation/
| |-- utils/
|-- experiments/
| |-- logs/
| |-- checkpoints/
| |-- configs/
|-- results/
| |-- figures/
| |-- tables/
| |-- metrics/
| |-- prediction_samples/
|-- docs/
| |-- paper/
| |-- methodology/
| |-- tutorials/
| |-- model_cards/
|-- tests/
| |-- unit_tests/
| |-- integration_tests/
| |-- prediction_tests/
|-- applications/
| |-- text_completion/
| |-- keyboard_suggestion/
```

7 Expected Outcomes and Novel Contributions

- **Primary Outcomes**
  - First RL-guided language model transfer system for Hindi-Chhattisgarhi next word prediction
  - Enhanced distillation techniques specifically designed for contextual language modeling tasks
  - Adaptation methods for leveraging high-resource language models for low-resource prediction tasks
  - Quantitative analysis of cross-lingual transfer effectiveness for next word prediction
- **Practical Applications**

  - Text completion systems for Chhattisgarhi users
  - Predictive keyboard implementations for mobile devices
  - Content suggestion tools for Chhattisgarhi writers
  - Foundation for developing other predictive language technologies

8 Technical Implementation Considerations

The objective of next word prediction requires careful consideration of several technical aspects:

- **Model Architecture:** an autoregressive language model architecture suitable for next word prediction. Options include:
  - Adapted transformer decoder-only architectures (similar to GPT models)
  - Modified BERT-style architectures with prediction heads
  - Specialized architectures optimized for morphologically rich languages
- **Training Objective:** The training objective is masked language modeling and next token prediction:
  - Implementation of appropriate loss functions for next word prediction
  - Consideration of word-piece vs. character-based tokenization impacts
  - Integration of contextual understanding metrics into the evaluation pipeline
- **Evaluation Framework Adjustments:** Evaluation metrics must be redefined to focus on prediction quality:
  - Perplexity measurements across various text domains
  - Next-word prediction accuracy at different sequence positions
  - Contextual relevance and semantic coherence of predictions
  - User experience metrics for practical applications
- **Domain Adaptation Techniques:** Given the Bible-based parallel corpus:
  - Implement domain adaptation strategies to extend model capabilities beyond religious text
  - Develop vocabulary expansion mechanisms to handle modern terminology not present in the Bible corpus
  - Create specialized evaluation metrics that assess both in-domain and out-of-domain performance

This approach has the goal of supporting the "poor sister" language through knowledge transfer from its "rich cousin" while offering a streamlined and focused implementation path. By focusing the project on next word prediction while maintaining the cross-lingual transfer learning approach, this roadmap provides a clear path to developing useful language technologies for Chhattisgarhi that leverage advances in Hindi natural language processing.

9 Conclusion

This revised roadmap transforms the original machine translation project into a focused next word prediction system while preserving the core cross-lingual transfer learning approach. The Project works on the innovative aspects of using reinforcement learning to guide knowledge distillation, but redirect them toward the specific challenges of language modeling rather than translation.

The project addresses the important goal of supporting low-resource languages through knowledge transfer from related high-resource languages, but with applications more directly relevant to everyday text input and composition tasks. This approach has the potential to create immediately practical tools for Chhattisgarhi speakers while advancing the state of research in cross-lingual knowledge transfer for language modeling.