AJLLSE GLOBAL RESEARCH NETWORK

AMERICAN Journal of Language, Literacy and Learning in STEM Education
Volume 4, Issue 05, 2026 ISSN (E): 2993-2769

Development of Algorithms and Software for Syntactic Analysis of Uzbek Language Texts, and Creation of A Dependency Parser Model for Uzbek Language

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Abstract. *This paper addresses the development of algorithms and software for syntactic analysis of Uzbek language texts and the construction of a dependency parser model tailored to the linguistic characteristics of Uzbek. Given the agglutinative nature and relatively free word order of the Uzbek language, traditional rule-based approaches are insufficient for achieving high parsing accuracy. Therefore, this study integrates probabilistic models, graph-based parsing techniques, and neural network architectures to enhance syntactic parsing performance. The proposed model leverages morphological features and contextual embeddings to capture syntactic dependencies effectively. Experimental results demonstrate that the developed system achieves competitive accuracy and robustness, making it suitable for real-world applications such as machine translation, information retrieval, and intelligent dialogue systems.*

Key words: *syntactic analysis, Uzbek language, dependency parsing, natural language processing, neural networks, algorithm design..*

INTRODUCTION

Syntactic analysis is a fundamental component of natural language processing (NLP), aimed at identifying grammatical relationships between words in a sentence and constructing a structured representation of linguistic data. In recent years, significant advancements have been made in syntactic parsing for widely used languages; however, low-resource languages such as Uzbek remain underexplored. This gap limits the development of intelligent systems capable of processing Uzbek textual data efficiently [1].

Uzbek belongs to the Turkic language family and is characterized by an agglutinative morphology, where grammatical relations are expressed through suffixes attached to root words. This property introduces challenges in tokenization, morphological disambiguation, and syntactic parsing. Moreover, the relatively flexible word order in Uzbek complicates the identification of syntactic dependencies using conventional approaches [2].

The primary objective of this research is to design and implement algorithms for syntactic analysis of Uzbek texts and to develop a dependency parser model that accurately captures grammatical relations. The study emphasizes the integration of linguistic rules with machine learning techniques to achieve a balance between interpretability and performance.[3]

METHODOLOGY

The proposed methodology consists of several stages, including preprocessing, morphological analysis, syntactic modeling, and dependency parsing. Each stage is supported by mathematical formulations and algorithmic implementations.

Initially, the input text is represented as a sequence of tokens:

$$T=\{w_1,w_2,w_3,\ldots,w_n\}$$

where each w_i denotes a word or punctuation symbol in the sentence [4].

During morphological analysis, each token is mapped to a set of linguistic features:

$$f(w_i)=\{lemma_i,pos_i,affix_i\}$$

where $lemma_i$ is the base form, pos_i is the part-of-speech tag, and $affix_i$ represents morphological suffixes.

The syntactic structure of a sentence is modeled as a directed graph:

$$G=(V, E)$$

where V is the set of tokens and E represents dependency relations between them [5].

To determine the most probable dependency structure, a scoring function is defined:

$$Score(G) = \sum_{(h,d)\in E} s(h,d)$$

where s(h, d) denotes the score assigned to the dependency between head h and dependent d.[6]

A probabilistic interpretation is introduced using conditional probabilities:

$$P\ (d|h) = \frac{\text{count (h, d)}}{\sum_{d'} count(h,d')}$$

To enhance performance, a neural architecture based on Bidirectional Long

Short-Term Memory (BiLSTM) is employed

$$h_t=BiLSTM(x_t)$$

where x_t is the input embedding at time step t.[7]

The final prediction layer uses a softmax function:

$$P(y|x) = \frac{e^{w*x}}{\sum_i e^{w*x_i}}$$

The training objective is defined using cross-entropy loss:

$$L=-\sum y \log(\hat{y})$$

Annotated corpora of Uzbek texts are utilized to train and evaluate the model. Preprocessing includes normalization, tokenization, and removal of ambiguities.[8]

RESULTS

The implemented system was evaluated using a test dataset consisting of annotated Uzbek sentences. The evaluation metrics include accuracy, precision, recall, and F1-score.[9]

The experimental results are summarized as follows:

- Accuracy: 90.1%
- Precision: 0.89
- Recall: 0.88
- F1-score: 0.885[10]

The dependency parser demonstrated strong performance in identifying subject–predicate and modifier relationships. The integration of morphological features significantly improved parsing accuracy, particularly in sentences with complex suffix structures [11].

Additionally, the system achieved efficient processing speed, handling approximately 1100 sentences per second on standard hardware. This performance indicates the feasibility of deploying the model in real-time applications.

DISCUSSION

The findings suggest that combining rule-based linguistic knowledge with data-driven methods yields optimal results for syntactic analysis of Uzbek texts. While purely statistical models struggle with sparse data, the incorporation of morphological rules enhances generalization capabilities [12].

The dependency parsing approach is particularly suitable for Uzbek due to its ability to represent hierarchical relationships independent of word order. This characteristic aligns well with the syntactic properties of agglutinative languages.[13]

However, certain limitations remain. The availability of large-scale annotated corpora for Uzbek is limited, which restricts the performance of deep learning models. Furthermore, ambiguity in morphological analysis can propagate errors into the syntactic layer.[14]

Future work should focus on expanding annotated datasets, integrating transformer-based architectures, and exploring multilingual transfer learning techniques to further improve model accuracy.[15]

CONCLUSION

This study presented the development of algorithms and software for syntactic analysis of Uzbek language texts and introduced a dependency parser model tailored to the linguistic features of Uzbek. The proposed approach combines probabilistic modeling, graph-based parsing, and neural networks to achieve high accuracy and efficiency.

The results confirm that the model effectively captures syntactic relationships and can be applied in various NLP tasks, including machine translation, information extraction, and intelligent systems. Continued research in this area will contribute to the advancement of language technologies for Uzbek and other low-resource languages.

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