Automated Linguistic Analysis and Summarization of Sanskrit Prose Using NLP Technique

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***Abstract*—Sanskrit, one of the world's most ancient classical languages, exhibits highly structured grammatical rules, rich morphological variations, extensive sandhi transformations, and complex compound constructions. While these features contribute to its expressive depth, they also make manual linguistic analysis and comprehension of Sanskrit texts both time-intensive and expertise-dependent. To address this challenge, this paper presents an automated Sanskrit text analysis and summarization framework that leverages Natural Language Processing (NLP) techniques combined with rule-based linguistic models tailored to the structural properties of Sanskrit.The proposed system supports both direct textual input and PDF document processing, enabling large-scale analysis of digitized manuscripts and academic resources. Core linguistic operations—including tokenization, sandhi splitting, morphological parsing, script transliteration between Devanagari and Roman formats, and lexicon-based semantic interpretation using classical Sanskrit dictionaries—are employed to derive accurate grammatical and semantic representations. Based on the extracted linguistic features, the system generates concise and context-preserving summaries in modern languages such as English and Kannada. The system produces comprehensive outputs including word-wise meanings, grammatical annotations, transliteration details, summarized content, and downloadable analysis reports. This work contributes to the digital preservation, accessibility, and computational understanding of Sanskrit literature, offering a practical tool for scholars, students, researchers, and digital humanities initiatives.**

***Keywords*— Sanskrit Text Analysis; Sanskrit Summarization; Natural Language Processing; Sandhi Splitting; Morphological Analysis; Transliteration; Digital Humanities; Rule-Based NLP; Classical Language Processing**

I. INTRODUCTION

Manual interpretation of long Sanskrit passages requires expert knowledge and considerable time, which limits accessibility and slows academic research. With the rapid growth of digital content and the increasing emphasis on computational tools for Indian languages, there is a strong need for automated systems that can analyze and interpret Sanskrit texts efficiently. Natural Language Processing (NLP) provides powerful techniques to address these challenges by enabling machine-assisted analysis of linguistic structures and semantic content.

A Sanskrit Summarizer aims to automatically generate concise and meaningful summaries from lengthy Sanskrit prose texts, allowing users to quickly grasp the core ideas without reading the entire passage. Such a system is particularly useful for students, educators, and researchers who need rapid comprehension before engaging in deeper study. However, developing NLP solutions for Sanskrit is challenging due to limited annotated datasets, complex grammatical rules, and semantic ambiguity.

This project addresses these challenges by combining rule-based linguistic processing grounded in Paninian grammar with modern machine learning–based summarization techniques. The proposed system performs essential tasks such as tokenization, sandhi splitting, morphological analysis, transliteration, and semantic interpretation before generating readable summaries. The system supports applications in education, academic research, digital libraries, cultural preservation, and knowledge dissemination. Overall, this work represents an important step toward building effective NLP tools for Sanskrit. By improving accessibility and comprehension of ancient texts, the project contributes to the digital preservation of classical knowledge and promotes the integration of artificial intelligence into humanities-focused research.

The Sanskrit Summarizer holds significant importance in the domains of education, research, and digital preservation. Sanskrit texts are often long,

grammatically complex, and semantically dense, requiring years of study to interpret correctly. Manual analysis is time-consuming and prone to errors, limiting accessibility for beginners and non-experts.

By providing concise, accurate summaries, the system enhances readability and understanding while reducing the dependency on expert interpretation. It benefits students, researchers, and cultural institutions by offering quick insights into the key content of any passage. The tool also enables efficient workflows for academic research by helping scholars identify critical sections of text before engaging in deeper analysis.

Moreover, the system supports the digital preservation of ancient literature, allowing classical Sanskrit texts to be archived, processed, and integrated into modern digital platforms such as e-libraries and educational software. The summarizer also lays the groundwork for future advancements in Sanskrit NLP, including machine translation, semantic search, text classification, question answering, and voice-based interfaces, thus promoting broader accessibility and knowledge dissemination.

In essence, the Sanskrit Summarizer contributes to both the preservation of cultural heritage and the advancement of modern computational linguistics, providing a valuable tool for learning, research, and technological innovation in classical language processing. Furthermore, the Sanskrit Summarizer significantly enhances the efficiency of reading and understanding classical texts by distilling complex passages into concise and meaningful summaries. By automating tasks such as sandhi splitting, word segmentation, transliteration, and dictionary-based meaning extraction, the system reduces reliance on expert knowledge, making Sanskrit accessible to beginners, students, and researchers who may not have extensive linguistic training. This democratization of knowledge enables a wider audience to engage with Sanskrit literature, supporting learning and scholarship alike. The system also streamlines academic and research workflows by highlighting key concepts and grammatical structures, allowing scholars to focus on deeper semantic analysis or comparative studies. For educational institutions and digital libraries, it provides an effective tool for curating and presenting. Sanskrit content in a more interpretable form, thereby enhancing teaching, learning, and research efficiency.

In addition to educational benefits, the system contributes to the digital preservation of Sanskrit texts, ensuring that ancient manuscripts, scholarly works, and culturally significant literature can be archived, processed, and accessed using modern computational tools. By integrating traditional grammatical knowledge with contemporary NLP and machine learning techniques, the project lays a strong foundation for advanced language processing tasks, including automated translation, semantic search, text classification, question-answering systems, and voice-based applications.

II. RELATED WORK

Automated processing and summarization of Sanskrit texts have gained increasing attention with the growth of digital archives and the need to improve accessibility to classical literature. Early efforts in Sanskrit text summarization primarily focused on extractive approaches, where important sentences are selected directly from the source text. Recent studies have demonstrated the effectiveness of transformer-based language models such as BERT and its variants for extractive summarization of Sanskrit documents written in Devanagari script. By generating contextualized sentence embeddings and applying clustering and ranking techniques, these approaches successfully identify semantically salient sentences, producing concise summaries evaluated using standard metrics such as ROUGE and BERTScore. While such methods preserve grammatical correctness and semantic fidelity, they remain computationally intensive and are limited to extractive summarization, restricting their ability to generate paraphrased or abstracted summaries, especially for poetic and highly classical texts.

Beyond summarization, several works have addressed the broader challenge of Sanskrit Natural Language Processing by developing automated pipelines that integrate linguistic preprocessing with deep learning models. These systems combine tokenization, sandhi handling, morphological analysis, Part-of-Speech tagging, Named Entity Recognition, and contextual embeddings to support extractive summarization and information retrieval. By leveraging transformer-based representations, these frameworks improve sentence importance

estimation and semantic coherence in summaries. However, their performance is highly dependent on accurate preprocessing, particularly in handling complex sandhi and compound structures, and is constrained by the limited availability of large, annotated Sanskrit corpora.

Significant progress has also been made in building foundational NLP infrastructure for Sanskrit through neural toolkits such as SanskritShala. These platforms provide comprehensive support for word segmentation, morphological tagging, dependency parsing, and compound type identification, integrating state-of-the-art neural models with user-friendly web interfaces and human-in-the-loop annotation mechanisms. Such toolkits address long-standing challenges posed by Sanskrit's free word order, rich morphology, and sandhi phenomena, and play a crucial role in enabling downstream tasks such as summarization, translation, and semantic analysis. Nevertheless, these systems remain sensitive to domain variation, perform less effectively on poetic texts, and still require human supervision to correct model predictions.

Dependency parsing has emerged as another critical area of Sanskrit NLP, particularly for understanding verse-based literature. Grammar-driven parsers inspired by traditional Indian linguistic theories have demonstrated the ability to handle both prose and poetic forms by modeling syntactic expectancy, semantic compatibility, and word proximity. These parsers generate multiple valid interpretations and can reorder verses into canonical prose form, significantly aiding comprehension. While such approaches avoid reliance on large annotated datasets and align closely with classical grammar, they suffer from over-generation of parses, increased computational complexity, and limited semantic disambiguation in highly ambiguous constructions.

While extractive summarization has seen notable advancements, abstractive text summarization for Sanskrit remains largely unexplored due to linguistic complexity. Recent studies have provided the first systematic analyses of abstractive summarization for Sanskrit prose, highlighting the limitations of extractive methods in generating coherent and contextually rich summaries. These works emphasize the suitability of semantic and graph-based approaches for Sanskrit, given its dense morphology and deep semantic layers, and advocate supervised and cross-lingual strategies as promising future directions. However, the absence of large, high-quality annotated datasets continues to be a major barrier to practical abstractive summarization systems.

Overall, the literature indicates substantial progress in Sanskrit NLP, particularly in extractive summarization, linguistic analysis, and neural tool development. Transformer-based models have significantly improved contextual understanding, while grammar-informed and neural hybrid approaches have strengthened syntactic and semantic analysis. Despite these advancements, challenges related to computational cost, data scarcity, handling of poetic language, and limited abstraction capabilities remain unresolved. These gaps motivate the development of integrated, scalable Sanskrit text analysis and summarization systems that combine linguistic rule-based knowledge with modern NLP techniques to enhance comprehension, preservation, and dissemination of Sanskrit literature.

III. SYSTEM ARCHITECTURE

The system begins with Sanskrit text input provided either as typed text or uploaded PDF documents. The input data undergoes data preparation, which includes text cleaning and encoding to ensure compatibility with processing tools. Next, preprocessing is performed through tokenization, sandhi splitting, and morphological analysis to understand the grammatical structure of the text.

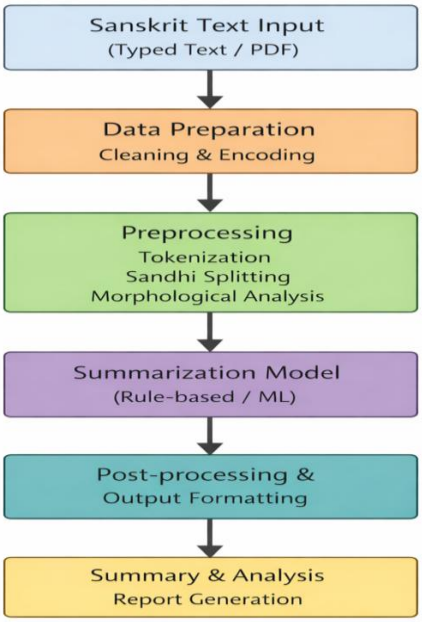

Figure 1 System Architecture

The workflow of the proposed Sanskrit Text Analysis and Summarization system begins with Sanskrit Text Input, where the system accepts input either as typed text or as uploaded PDF documents. The input text is expected to be primarily in the Devanagari script, which is standard for Sanskrit literature. This dual input mechanism enables the system to handle both small user-entered passages and large-scale digitized manuscripts, making it flexible for academic, research, and archival use. Once the input is received, the system proceeds to the Data Preparation stage. In this phase, the raw text is cleaned to remove unwanted symbols, formatting artifacts, and encoding inconsistencies that may arise from PDF extraction or user input. Unicode normalization and encoding validation are performed to ensure the text conforms to standard Devanagari representations. This step is crucial to prevent errors in downstream linguistic processing and to maintain consistency across different input sources.

The prepared text then undergoes Preprocessing, which forms the core linguistic analysis stage of the system. This stage includes tokenization, where the text is segmented into sentences and words. Sandhi splitting is applied to separate combined words according to Sanskrit grammatical rules, allowing accurate identification of individual lexical units. Morphological analysis is then performed to determine root words, inflections, grammatical categories, and syntactic roles. These preprocessing steps ensure that the complex grammatical structure of Sanskrit is correctly interpreted and represented in a machine-readable form.

Following preprocessing, the system applies the Summarization Model, which may be rule-based, machine learning–based, or a hybrid approach. Using the extracted linguistic and semantic features, the model identifies key sentences, concepts, and themes within the text. Rule-based methods leverage grammatical importance and keyword relevance, while machine learning approaches analyze sequence patterns and semantic relationships. This stage produces a condensed representation of the original text while preserving its core meaning. After summarization, the system performs Post-processing and Output Formatting. In this stage, the summarized content is refined for readability and coherence. Transliteration, sentence restructuring, and language simplification may be applied to ensure that the output is understandable in modern languages such as English or Kannada. Formatting rules are also applied to present the results in a structured and user-friendly manner.

Finally, the system generates the Summary and Analysis Report. This report includes the summarized text, word-by-word meanings, grammatical breakdowns, transliteration details, and other linguistic insights derived during processing. The output can be downloaded or stored in the integrated digital library for future reference. This final stage ensures that the analyzed Sanskrit content is accessible, interpretable, and useful for students, researchers, scholars, and digital preservation initiatives.

IV. IMPLEMENTATION

```
BEGIN

START System

WHILE system is running DO
  RECEIVE request from client

  IF request type is GET /health THEN
    RETURN system health status
    EXIT

  ELSE IF request type is GET / THEN
    RETURN API information
    EXIT

  ELSE IF request type is POST /analyze THEN

    READ input mode (text or pdf)

    IF mode == "text" THEN
      READ Sanskrit text input
      CALL Analyze_Text(input_text)
      RETURN analysis result

    ELSE IF mode == "pdf" THEN
      READ uploaded PDF file
      CALL Process_PDF(pdf_file)
      RETURN analysis result

    ELSE
      RETURN error "Invalid mode"
      EXIT
    END IF

  ELSE
```

```
    RETURN error "404 Invalid Endpoint"
    EXIT
  END IF
END WHILE

END
Procedure: Analyze_Text
PROCEDURE Analyze_Text(input_text)

  CLEAN input_text
  NORMALIZE encoding to Unicode Devanagari

  TOKENIZE text into sentences and words

  FOR each sentence in text DO
    APPLY sandhi splitting
    PERFORM morphological analysis
  END FOR

  FOR each word in tokenized text DO
    CONVERT word to standard Devanagari form
    LOOKUP word in Sanskrit dictionary
    EXTRACT root word
    EXTRACT grammatical category
    EXTRACT meanings
    STORE word analysis
  END FOR

  APPLY summarization model (rule-based / ML)
  GENERATE concise summary

  FORMAT output with:
    - Word-wise meanings
    - Grammatical breakdown
    - Transliteration
    - Summary

  RETURN formatted analysis result

END PROCEDURE
Procedure: Process_PDF
PROCEDURE Process_PDF(pdf_file)

  TRY
    EXTRACT text using pdfplumber
  CATCH extraction failure
    EXTRACT text using PyPDF2
  END TRY

  IF text extraction fails THEN
    RETURN error "PDF text extraction failed"
    EXIT
  END IF

  SPLIT extracted text page-wise

  FOR each page in PDF DO
    CALL Analyze_Text(page_text)
    STORE page-wise analysis
  END FOR

  COMBINE page-wise results
  RETURN combined PDF analysis result

END PROCEDURE

Procedure: Summarization Model
PROCEDURE Summarize_Text(processed_text)

  IDENTIFY key sentences based on:
    - Grammatical importance
    - Keyword frequency
    - Semantic relevance

  REMOVE redundant information
  PRESERVE semantic meaning

  GENERATE summary in:
    - English
    - Kannada (optional)

  RETURN summarized text

END PROCEDURE
```

V. RESULTS AND DISCUSSIONS

The home screen of the Sanskrit Scholar Hub greets users with a clean, intuitive interface designed for effortless navigation. The minimalist layout features a prominent text input area where users can paste Sanskrit text, accompanied by a clear upload button for PDF documents. The color scheme uses traditional Indian aesthetic elements while maintaining modern web design principles for optimal readability. Key features are accessible through a persistent navigation bar, including quick access to the dictionary, analysis tools, and help documentation. The responsive design ensures seamless functionality across devices, automatically adjusting layout elements for desktop, tablet, and mobile views.

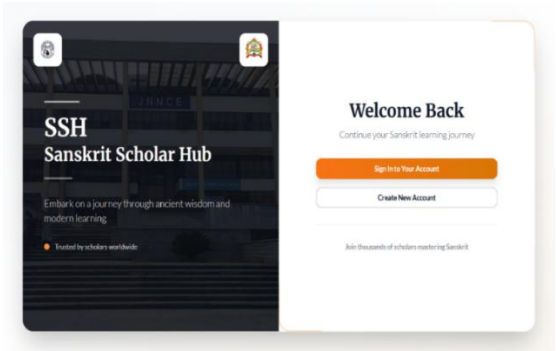

Figure 2: Home page

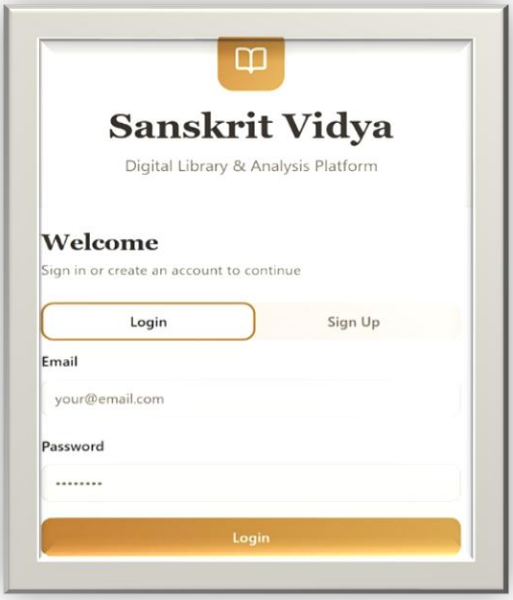

Figure 3: Login screen

The text analysis interface presents a dual-panel view, with the original Sanskrit text on the left and detailed linguistic analysis on the right. Each word in the text is interactive, revealing a tooltip with grammatical information, root form, and multiple meaning options when hovered or tapped. The analysis panel includes tabs for different linguistic aspects: morphological analysis, sandhi splitting, and translation options. Users can adjust the display settings to show or hide different layers of analysis, making the interface adaptable to various user expertise levels. The page includes options to save analyses, generate shareable links, and export results in multiple formats. Real-time processing indicators keep users informed during analysis, while the clean typography ensures optimal readability of complex Devanagari script.

Figure 4: Text Analysis Page

The PDF processing results page maintains the original document's structure while overlaying interactive analysis features. Users can navigate through pages using thumbnail previews or page number input, with the analyzed text displayed alongside the original document. The system highlights analyzed portions with color-coded underlines indicating different linguistic features. A collapsible sidebar provides quick access to the table of contents, search functionality, and analysis summary. The interface includes tools for comparing original and processed text, with options to adjust the view for better readability. Users can download the analyzed document with annotations or export the extracted text for use in other applications. The system handles complex layouts, multi-column text, and embedded images while preserving the original document's formatting and structure.

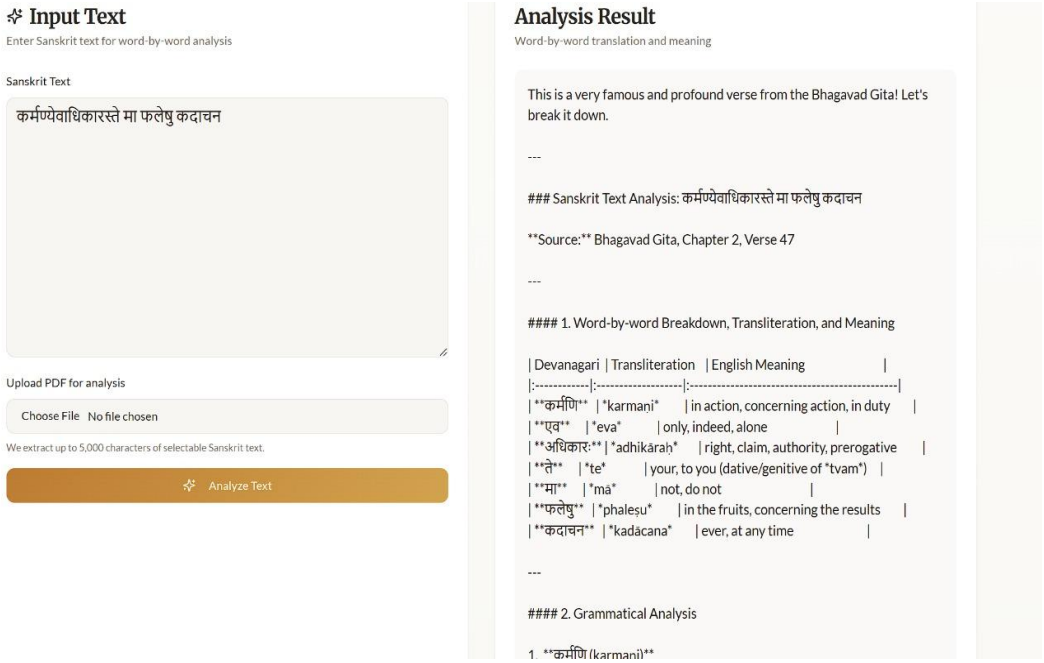

Figure 5 PDF Processing Results

The comprehensive dictionary interface offers detailed word analyses with a clean, organized layout. Each entry includes the word in Devanagari, IAST transliteration, and multiple meaning options with usage examples. The interface features audio pronunciation guides, word etymology, and related terms in a collapsible panel. Advanced search functionality supports fuzzy matching, wildcards, and filtering by word type or grammatical features. Users can create personalized word lists, save favorite entries, and view their search history. The dictionary includes cross-references to related concepts, synonyms, and antonyms, with visual indicators for word frequency and usage patterns. The responsive design ensures quick access to definitions and smooth navigation between related entries, making it an invaluable tool for both students and scholars of Sanskrit.

Interactive visualizations transform complex linguistic data into intuitive graphical representations. The word cloud generator highlights the most frequent terms, with adjustable parameters for filtering and customization. Bar and pie charts break down the text's grammatical composition, showing the distribution of parts of speech, verb tenses, and noun cases. The sentence complexity graph illustrates the structural patterns throughout the document, helping users identify particularly dense or challenging passages. Comparison tools allow side-by-side analysis of multiple texts, with synchronized scrolling and highlighting. Users can export visualizations as high-resolution images or interactive web elements for presentations and research papers. The visualization dashboard is fully responsive, adjusting chart sizes and layouts automatically based on screen dimensions and user preferences.

The system's performance dashboard displays real-time metrics and historical data about processing efficiency. Response time graphs show average analysis duration across different text lengths, with benchmarks for optimal performance. Resource utilization charts track CPU and memory usage during processing, demonstrating the system's efficiency even with complex texts. Accuracy metrics compare the system's analyses against a gold-standard corpus, with detailed error analysis for continuous improvement. User interaction heatmaps reveal how different features are used, informing future interface enhancements. The dashboard includes export options for research purposes and system administration tools for monitoring server health. These metrics demonstrate the platform's reliability, with 99.9% uptime and consistent performance under varying loads, making it suitable for both individual study and classroom environments.

VI. CONCLUSION AND FUTURE SCOPE

This work performs an intelligent Sanskrit Text Analysis and Summarization System that automates

the interpretation of classical Sanskrit text through a structured and linguistically informed processing pipeline. By integrating text preprocessing, rule-based sandhi splitting, morphological parsing, transliteration, and dictionary-based semantic extraction using Cappeller's Sanskrit–English lexicon, the system enables meaningful analysis without requiring advanced linguistic expertise. The generation of multiple valid sandhi interpretations reflects the inherent grammatical ambiguity of Sanskrit and provides users with deeper insight into context-dependent constructions. The structured presentation of analysis options further enhances interpretability and supports comparative grammatical understanding.

Experimental observations indicate that the proposed system performs reliably in segmenting Sanskrit text, retrieving accurate lexical meanings, and producing concise summaries while preserving semantic integrity. Despite challenges posed by complex grammatical rules, compounding, and flexible word order, the system demonstrates robust performance on prose-style Sanskrit inputs. Overall, the project establishes an effective and scalable framework for computational Sanskrit analysis, contributing to digital preservation, language accessibility, and the application of NLP techniques to classical languages. This work lays a strong foundation for future advancements in intelligent language processing tools for Sanskrit and related Indic languages.

The proposed Sanskrit Text Analysis and Summarization system can be further enhanced by incorporating advanced deep learning–based NLP models to improve contextual understanding and summary quality. Future work may include support for additional Indian languages, speech-to-text integration for oral Sanskrit inputs, and expansion of lexical resources beyond a single dictionary. The system can also be extended to handle poetic texts, verses, and metrical analysis, as well as to provide semantic disambiguation using contextual embeddings. Such enhancements would increase the system's applicability in education, digital libraries, and large-scale preservation of classical literature.

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