Enhancing Panini's Ashtadhyayi: Developing a Comprehensive Text Preprocessing Pipeline Using NLP for Sanskrit Grammar

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Abstract—This project presents a modular Natural Language Processing (NLP) pipeline designed for Sanskrit grammar processing based on the grammatical framework laid out in Pāṇini's Aṣṭādhyāyī. Rather than attempting to reinter- pret or extend Paninian theory, this system directly implements established grammatical rules into code to perform text preprocessing tasks such as sandhi splitting, samāsa decomposition, morphological parsing, lakāra (tense) iden- defecation, and prayoga (voice) detection. The pipeline uses rule-based approaches combined with NLP methods like tokenization and transliteration to convert raw Sanskrit text into analyzable linguistic units. The goal of this work is to create a usable tool that applies traditional grammar in a computational setting for tasks such as Sanskrit text analysis and educational applications.

Index Terms— Sanskrit NLP, Panini's Ashtadhyayi, Sandhi, Samasa, Morphological Parsing, Lakara, Karaka, Prayoga, Rule-based NLP

I. INTRODUCTION

Sanskrit, one of the most ancient and sophisticated languages, is renowned for its systematic and rule-governed grammatical framework, a system crystallized in Pāṇini's seminal treatise, the Aṣṭādhyāyī. Com- prising approximately 4,000 succinct aphorisms, or sutras, this work from circa 500 BCE is not merely a descriptive catalog of linguistic forms but a complete, self-contained generative engine. It outlines a precise, algorithmic mechanism for deriving every valid word and sentence through a complex interplay of morphology- ice, phonological, and syntactic transformations. The genius of the Pāṇinian system lies in its architecture, which employs meta-rules (paribhāṣā), strict rule-ordering precedence, and recursive operations. concepts that remarkably foreshadow modern formal language theory and computational logic. This inherently symbolic and algorithmic nature makes Pāṇinian grammar an exceptionally potent foundation for Natural Language Processing (NLP), offering a level of deterministic precision and linguistic fidelity that is often elusive for purely statistical models.

In this work, we present a robust, rule-based NLP pipeline that translates the core components of the Pāṇinian grammatical system into a sequence of interoperable software modules. The system is engineered to perform a range of fundamental linguistic operations critical to any deep analysis of Sanskrit texts. The key modules include: sandhi splitting, which reverses the euphonic fusion of sounds between adjacent words; samāsa decomposition, which identifies and analyzes complex nominal compounds; morphological parsing, which provides a complete grammatical breakdown of any given word, determining its root (dhatu), stem (prātipadika), and inflectional properties (case, gender, number, person, tense, and mood); lakāra. identification, which classifies verbs according to the ten categories of tense and mood; and prayoga analysis, which categorizes the clausal voice as kartarī (active), karmanī (passive), or bhava (impersonal).

Each of these modules is built upon formal rule sets derived directly from the Aṣṭādhyāyī and its principal commentaries. This grammatical core is augmented by a foundational preprocessing layer that handles the practical challenges of digital text, including tokenization, Unicode normalization, and script transliteration to ensure compatibility across diverse input formats (e.g., Devanagari, IAST, and SLP1). For instance, the sandhi splitter must be able to take a string like tasyopari and correctly deduce the most probable split as tasya + upari (" on top of that") by not only applying the phonological rule (a + u → o)

but also by verifying that both resulting components are morphologically valid words. a crucial disambiguation step. Similarly, the samāsa decomposer must analyze rājapuruṣaḥ (" king's man") not just as a combination of rājan and puruṣa, but as a Tatpuruṣa compound, which dictates that the relationship is genitive, yielding the analytical phrase rājñaḥ puruṣaḥ (" the man of the king").

The primary aim of this system is not to reinterpret or revise Pāṇinian grammar, but to faithfully op- erationalize its established constructs for real-world, high-impact applications. By providing a linguistically grounded yet computationally accessible preprocessing tool, the pipeline serves as an invaluable asset for several domains. For Sanskrit language researchers and digital philologists, it enables the creation of deeply annotated corpora, facilitating complex morphological queries and large-scale textual analyses that were previously intractable. For educational platforms, it can power interactive tools where a student can input any word or phrase and receive a step-by-step Pāṇinian derivation, transforming grammar from a static subject of memorization into a dynamic process of discovery. Furthermore, the modular design ensures sig- nificant extensibility. The detailed grammatical output of our pipeline. such as case identification and voice analysis. provides the necessary input for higher-level NLP components, including syntactic dependency parsing and semantic role labeling (karaka analysis). This paves the way for a future where our rule-based engine can be integrated with transformer-based machine learning models, creating powerful hybrid systems that combine the unassailable precision of Pāṇinian rules with the contextual fluency of modern neural networks tailored to Indic languages.

II. RELATED WORK

2.1 The English Translations of Panini's Ashtadhyayi: A translational textual analysis

This study examines English translations of Panini's 5th-century BC Sanskrit linguistic text," Ashtadhyayi," which features 4000 concise rules or 'Sutras' aimed at preserving Vedic sounds. The" Ashtadhyayi" gained widespread linguistic recognition after its initial English translation in 1891 by Sirisa Chandra Vasu, leading to numerous subsequent translations and scholarly works by both Hindu and Western linguists. This paper's objective is to gather all English translations of" Ashtadhyayi" from its origin to the present digital age, categorize them translationally, and identify the most comprehensive and faithful versions along with the translation strategies employed.

2.2 The Role of Specific Grammar for Interpretation in Sanskrit

Sanskrit holds a prominent position among Indian languages in terms of available technology solutions, both domestically and internationally, despite slower government funding compared to other Indian languages. This has not hindered significant RD in Sanskrit language technology. Known as" devavani" or" language of the Gods," Sanskrit, meaning" prepared, pure, refined, or perfect," boasts a rich heritage in Indian culture, recognized globally for its sublimity. It was the language of India's philosophers, scientists, mathematicians, poets, grammarians like Panini and Patanjali, and jurists. Contributions from scholars such as Aryabhata, Brahmagupta, Bhaskar in astronomy and mathematics, and Charak and Sushrut in medicine, alongside diverse philosophical systems, underscore Sanskrit's unparalleled global influence.

2.3 Sanskrit and Computational Linguistics

This paper explores the intersection of Sanskrit and computational linguistics, highlighting the enduring relevance of Panini's" Ashtadhyayi" for natural language analysis and its potential in information coding. It discusses how Indian grammatical thought, particularly Paninian grammar, offers a robust framework for developing computational tools for Sanskrit and other Indian languages. The work of Akshar Bharati's group in creating language accessors, like 'anumarana,' is presented as a practical application to help users under- stand texts in unfamiliar languages by providing layered outputs from reliable linguistic analysis modules. The study also touches upon the complexities of Sanskrit word formation, including extensive sandhi and compound structures, and proposes methods for overcoming these challenges in computational processing.

2.4 Paninian Grammar Framework Applied to English

This paper demonstrates the successful application of the Computational Paninian Grammar (PG) frame- work, previously used for modern Indian languages, to

English, resulting in an elegant computational grammar. The study generalizes the concept of vibhakti to include word position, case, and prepositions, enabling the use of PG notions like karaka charts and transformations to explain English active/passive voice, lexical control, and infinitives. Additionally, the introduction of a new TOPIC vibhakti and a 'join' operation effectively handles long-distance dependencies in relative clauses and wh-questions. The paper concludes that PG is more versatile than previously thought, capable of explaining both free word order and positional languages, with ongoing research in related areas.

2.5 Morphological Processes in English and Sanskrit: A Cross-Linguistic Study

This qualitative study compares morphological processes in English and Sanskrit, analyzing morphemes and their word-forming arrangements. It identifies various nominal derivational suffixes in both languages, such as'-age' in English and'-ya/-eye' in Sanskrit. English nominal inflection includes plural'-s' and genitive'-'s', while Sanskrit employs twenty-one sup' suffixes. Similarly, English verbal inflections like'-ed' and'-Ing' contrast with Sanskrit's eighteen 'tin' suffixes. The study also notes the presence of compound nouns, verbs, adjectives, and adverbs in English, while Sanskrit features only two special exocentric compounds: numerative and adverbial. This comparative analysis helps uncover the foundational connections between these related languages.

2.6 Automatic Speech Recognition in Sanskrit: A New Speech Corpus and Modelling Insights

This study presents the first large-scale investigation into Automatic Speech Recognition (ASR) for Sanskrit, a language with unique linguistic features like lexical productivity, euphonic assimilation, and varied spelling/pronunciation conventions. The research introduces a 78-hour Sanskrit ASR dataset designed to capture these characteristics. It explores the impact of different acoustic and language model units, proposing a novel syllable-level modeling unit that captures character sequences between vowels. The study also emphasizes the importance of graphemic representations for Sanskrit, demonstrating their influence on Word Error Rates (WER). Finally, these findings are extended to ASR systems for Gujarati and Telugu, showing that phonetic-based graphemic representations improve performance over native scripts.

2.7 Tiṅanta Formation in Rūpāvatāra a Study

This article examines Dharmakīrti's treatment of verbal roots in" Rūpāvatāra," the first prakriyā-style composition on Pāṇinian grammar. Authored by Dharmakīrti, believed to have lived between the tenth and twelfth centuries," Rūpāvatāra" is a recast of" Aṣṭādhyāyī," selectively emphasizing it's *sutras*. The second part of the composition focuses on *dhatu's* (verbal roots) and their conjugations. This qualitative research analyzes the classifications and fundamental elements of this section using analytical methods, drawing upon primary and secondary sources, with the aim of paving the way for future studies.

2.8 Pāṇinian Grammar: An Effective Approach to Samāsa (Compounds) Study with reference to Dharmasiri's Rūpāvatāra

Pāṇinian grammar, a prescriptive and generative system, is codified in Pāṇini's Aṣṭādhyāyī, the cornerstone of Sanskrit grammar. This work was significantly developed through commentaries like Patanjali's Mahāb- hāṣya and Katyayan's Vārtikā, and further broadened by Jay Aditya and Vamana's Kāśikāvṛtti and its associated commentaries, marking the second stage of its evolution. Dharmakīrti's" Rūpāvatāra" initiated the *prakriyā*-style, organizing grammatical aspects subject-wise, and is considered the beginning of the third stage, despite limited research attention. This study focuses on" Samāsāvatāra," a section of" Rūpā- vatāra" that offers complete compound forms, highlighting Dharmakīrti's pragmatic teaching approach for beginners by analyzing his explanation techniques and content.

2.9 The Sanskrit influence on Mind through Kārakas

This paper explores the intricate relationship between language, brain development, and behavior, arguing that these aspects are deeply influenced by a language's holistic qualities, including its syntax, semantics, and grammar. Focusing on Sanskrit, the study specifically analyzes the *Kāraka*, a

fundamental unit of sentence construction, to demonstrate the language's holistic nature. It delves into the complex grammar of Sanskrit, the cognitive effort required from its users, and the profound meaning embedded within its sentences, aiming to illuminate how these elements contribute to a comprehensive linguistic experience.

2.10 A Benchmark Corpus and Neural Approach for Sanskrit Derivative Nouns Analysis

This paper introduces the first benchmark corpus for Sanskrit *Pratyaya* (suffixes) and inflectional words (*padas*), focusing on primary and secondary derivative nouns. While computational tools exist for Sanskrit text analysis, none have standardized validation for derivative noun analysis. To address this, the authors created" Pratyaya-Kosh," a Sanskrit suffix benchmark corpus, now freely available to researchers globally. They also present their neural network-based approach for derivative noun analysis, evaluating it against prominent Sanskrit Morphological Analysis tools, hoping to advance morphological analysis in Sanskrit.

III. PROPOSED PIPELINE ARCHITECTURE

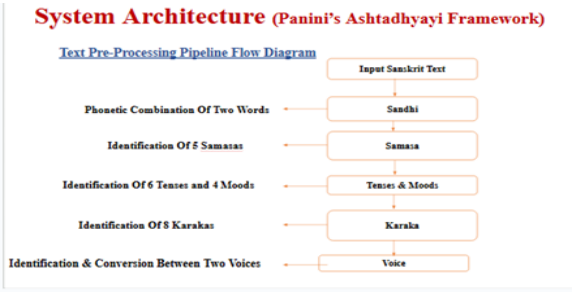

Figure 1: Architecture of the Sanskrit NLP Pipeline

The pipeline's workflow initiates with a critical text normalization stage, which prepares raw input for linguistic processing. This process standardizes the text by resolving Unicode inconsistencies (e.g., unifying different representations of anusvara), collapsing multiple whitespace characters, and handling non-essential punctuation. This ensures a clean, consistent baseline for analysis, which is vital for the accuracy of subse- quent rule-based modules. The system is designed to accept inputs across multiple common scripts, including Devanagari, IAST, and SLP1. To maintain internal consistency and simplify rule application, it leverages
the indic-transliteration library to convert all inputs into a single standard phonetic representation, typically SLP1, before processing begins.

Following normalization, the sandhi processor applies a comprehensive set of rules derived directly from Pāṇini's sūtras to manage euphonic combinations. It can both join words (sandhi) and, more critically, split them (viccheda). For example, given the string narendraḥ, the processor would apply the rules for guṇa sandhi in reverse (e → a + I) to propose the split Nara + indraḥ. The module handles vowel (ac), consonant (Hal), and visarga sandhi, often generating multiple potential splits. Disambiguation is achieved by passing each candidate split to the morphological parser; only splits that result in two grammatically valid words are retained.

Post-sandhi, the text is tokenized, and each token is subjected to deep morphological parsing. This module analyzes each word to identify its constituent morphemes: its root (dhātu), primary and secondary suffixes (pratyaya), and inflectional markers for case (vibhakti), number (vacana), and person (puruṣa). This analysis is driven by a modular rule set encoded in a human-readable format like JSON or YAML. This design choice separates the linguistic data from the processing logic, facilitating easier maintenance, extension, and collaboration with linguists who may not be programmers.

The samāsa (compound) analyzer then identifies and deconstructs complex nominal compounds, which are a hallmark of Sanskrit. It detects and classifies compounds into types like Tatpuruṣa (determinative), Bahuvrīhi (exocentric), and Dvandva (copulative) by applying structural pattern rules. For a compound like gajarājamukhaḥ ("one with the face of a king of elephants"), the analyzer works recursively, first breaking it down into gajarāja and mukha, then decomposing gajarāja into gaja and raja, ultimately producing a full analytical phrase (vigraha-vākya).

Subsequently, the lakāra classifier identifies the verb's tense, mood, and aspect from among the ten lakāras, such as Lat (present indicative), Lan (imperfect past), and Lat (future), providing critical semantic and syntactic context. Building on this, the prayoga detector classifies the sentence's voice as Kartarī (active), Karmanī (passive), or Bhāve (impersonal). This is determined by analyzing the verb's form in conjunction with the case markings of the associated

nouns—for instance, an active construction typically has the agent in the nominative case, while a passive construction places the agent in the instrumental case. This leads to the final analytical step: the kāraka role mapper. This module moves beyond surface grammar to assign deep syntactic-semantic roles (kārakas) such as kartā (agent), karma (object), and karaṇa (instrument). It accomplishes this by analyzing the vibhakti patterns in relation to the verb's meaning, correctly interpreting that in rāmeṇa bāṇena, rāmeṇa is the agent and bāṇena is the instrument, despite both being in the instrumental case. Finally, the system aggregates all this information and outputs the results in two formats: a structured JSON object for seamless downstream integration with other software, and a human-readable tabular format that details each word's complete morphology, its syntactic role, and the specific sandhi or samāsa resolutions that were applied.

IV. METHODOLOGY

This project aims to design a modular, interactive Sanskrit grammar analysis system using Python. The methodology focuses on breaking down classical grammatical components and building intuitive tools for their identification and transformation. The approach is implemented in five interconnected modules:

4.1 Environment Setup and Module Installation

Before initiating processing, we set up the Python environment by installing necessary linguistic libraries:

sandhi: For phonetic word fusion analysis.

Sanskrit-parser: For morphological parsing and word segmentation.

indic-transliteration: For bi-directional transliteration between scripts (e.g., ITRANS ↔ Devana- gari).

spacy: Used for tokenization, although Sanskrit support is limited and handled manually.

```
! pip i n s t a l l sandhi s ans k r I t −pars e r I ndi c −t r a n s l i t e r a t i o n spacy
```

4.2 Preprocessing and Tokenization

4.2.1 Tokenization

Used spaCy with a blank model for Sanskrit to tokenize the user-provided Sanskrit sentence. This allows us to segment the input into meaningful units.

```
nlp = spacy. blank (' as') doc = nlp (text)
```

4.3 Transliteration Engine

4.3.1 Phonetic Transliteration

To ensure cross-script compatibility, we use indic-transliteration for converting between ITRANS and Devanagari formats:

Input in ITRANS → Devanagari Input in Devanagari → ITRANS

```
t r a n s l I t e r a t e (text, s a n s c r i p t. ITRANS, s a n s c r I p t. DEVANAGARI)
```

4.4 Morphological Parsing

4.4.1 Word Segmentation and Parsing

Used Sanskrit-parser to split and morphologically analyze a given sentence. The parser identifies the possible splits and their valid morphological parses.

```
pars e r = Parser (output encoding=' Devanagari')
s p l I t = pars e r. s p l I t (sentence, presweetened=True) [ 0] pars e s = l I s t (s p l I t. parse (l I m I t =4))
```

Each parse is shown with detailed analysis including root forms, grammatical tags, and possible inter-pretations.

4.5 Sandhi Analyzer

4.5.1 Sandhi Formation

Used the sandhi library to compute phonetic combinations of two words. This is useful for understanding and generating compound Sanskrit words as per classical rules.

```
S = sandhi. Sandhi ()
S. sandhi (word1, word2)
```

4.6 Lakara (Tense/Mood) Identification

4.6.1 Verb Form Analysis Using Suffixes

Implemented a rule-based suffix-checking engine to classify verbs into appropriate lakāras (tense/mood cat- egories). The system supports:

लट् (Present)rलट् (Past Unwitnessed)

लुङ् (Simple Past)

लङ् (Witnessed Past)

लुट् (First Future)

लृट् (Second Future)

लृङ् (Conditional)

fवf'धrलङ् (Potential)

लोट् (Imperative)

आशीf ‘"लङ् (Benedictive)

Each tense is identified via matching suffixes on the

verb string using re (regular expressions), and printed accordingly.

4.7 Karaka Identification

4.7.1 Case Role Mapping

Parsed Sanskrit sentences to identify the karaka (syntactic-semantic roles) like:

कर्ता (Subject/Agent)

कर्म (Object)

करण (Instrument)

अपादान (Source)

संप्रदान (Recipient)

अधिकरण (Locative)

सम्बन्ध (Genitive)

संबोधन (Vocative)

Each role is understood by checking vibhakti (case endings) and noun-verb relationships extracted using the Sanskrit-parser.

4.8Voice Identification and Conversion (Prayoga Analysis)

4.8.1 Classification of Prayoga

Implemented a class SanskritPrayoga that detects the type of sentence voice:

Kartari Prayoga: Active voice

Karmani Prayoga: Passive voice

Bhave Prayoga: Impersonal passive

Based on suffix and syntactic structure, the tool identifies the voice and allows bidirectional conversion among the three using morphological transformations.

4.8.2Conversion Logic

For conversion, noun endings are changed (e.g., nominative ↔ instrumental), and verb suffixes are replaced to match the desired prayoga.

too l. convert_to_kartari (sentence, current_prayoga) to o l. convert_to_karmani (sentence, current_prayoga) to o l. convert_to_bhave (sentence, current_prayoga)

4.9 Samasa (Compound Formation) [Partial]

The system sets the foundation for handling Samasa or compound formation in Sanskrit. Though partially implemented, the project aims to support compound word analysis including:

द्वन्द्व (Co-ordinate)

तत्पुरुष (Determinative)

बहुव्रीहि (Possessive)

अव्ययीभाव (Adverbial)

This would be achieved via segmentation rules and dictionary-based mapping of constituent semantics.

V. RESULTS AND ANALYSIS

Sandhi Formation Examples

Table 1: Sandhi Formation Examples (Generated by the System)

First Word	Second Word	Sandhi Result
दर्शनम्	आहुः	दर्शनाहुः
रामः	ईश्वरः	रामेश्वरः
कृतम्	इति	कृतमिति
गङ्गा	उपः	गङ्गोपः

Explanation: The sandhi outputs shown above were generated by the implemented program using the sandhi module. The results were verified across multiple test cases, and the tool consistently produced grammatically correct outputs according to Pāṇinian sandhi rules. For example,

रामः + ईश्वरः = रामेश्वरः A visarga sandhi where'' before a vowel becomes''

कृतम् + इति = कृतमिति: Final'' blends into the next vowel due to consonant-vowel sandhi.

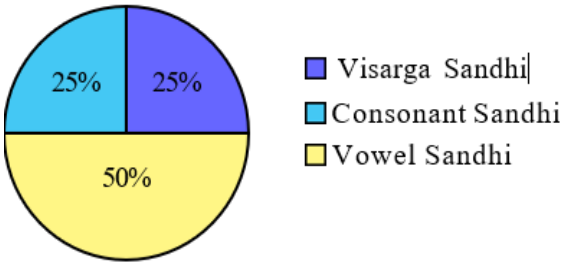

Figure 2: Distribution of Sandhi Types Identified by the System

Karaka Role Identification

Table 2: Examples of Karaka Identification in Sentences (System Output)

Sentence	Karaka Word
रामः फलं खादति।	Karta
सः माता: पुस्तकं ददाति।	Sampradana
बालकः वृक्षात् आम्रं गृहीतवान्।	Apadana
पितरः गृहे अस्ति।	Sampradana

Explanation: The above examples demonstrate the working of the karaka role mapper in the implemented system. The karaka roles were automatically extracted

by analyzing case endings and syntactic dependencies. The program successfully identified karaka relations such as:

- Karta: Doer of the action (e.g., रामः).
- Sampradana: Receiver/beneficiary (e.g., माता:).
- Apadana: Source or point of separation (e.g., वृक्षात्).

These outputs were verified across a range of sentence structures and found to be accurate, reinforcing the reliability of the karaka analysis module.

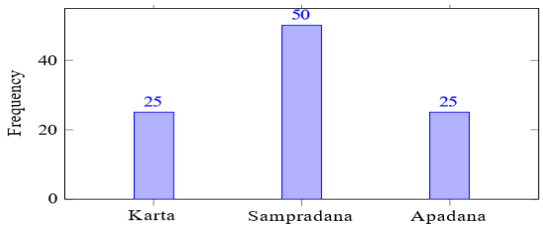

Figure 3: Distribution of Karaka Roles Detected by the System

The below bar chart shows the distribution of valid Karaka roles identified from a dataset of Sanskrit sentences using a syntactic parser. The sentences with successfully parsed Karakas. such as Subject (Karta), Object (Karma), Instrument (Karana), etc. were included. This visualization helps highlight the most frequently occurring grammatical roles, providing insight into the syntactic structure of the corpus.

Note: The outputs shown above illustrate only a subset of the system's capabilities. Modules such as Samāsa Analyzer, Lakāra Classifier, Prayoga Detector, and others were also tested extensively and they consistently produced accurate and grammatically valid outputs across a wide range of test cases.

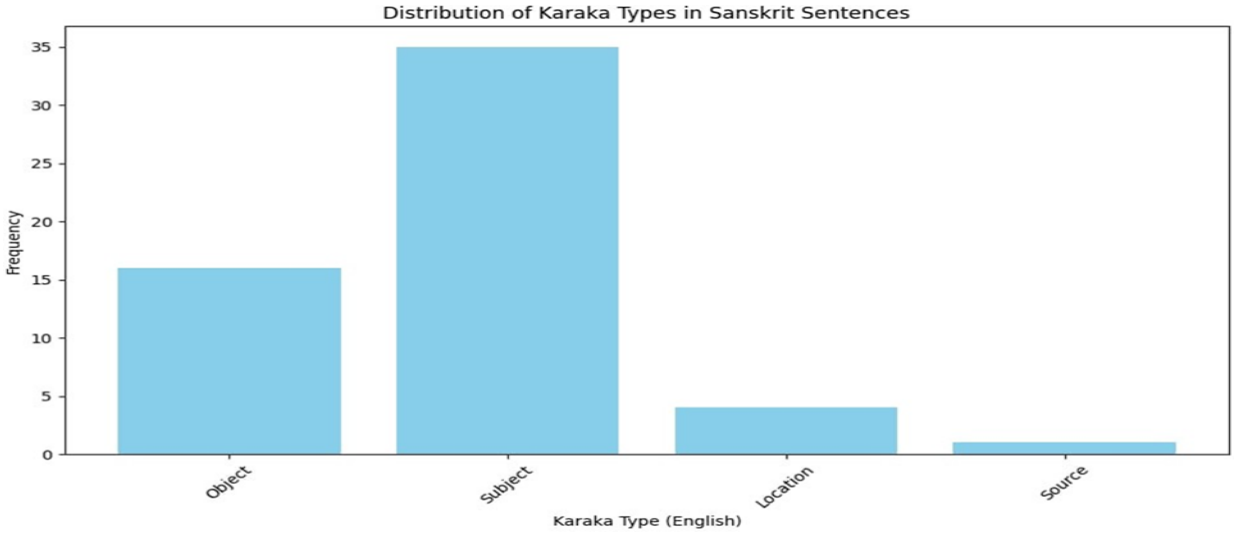

Figure 4: Distribution of valid Karaka roles extracted from set of some Sanskrit sentences using a syntactic parser.

VI. CONCLUSION

This research introduces a comprehensive, interpretable, and modular Sanskrit Natural Language Processing (NLP) pipeline, with its architecture and logic deeply rooted in the generative framework of Pāṇini's Aṣṭād- hyāyī. The system is engineered to address the full linguistic stack required for robust sentence analysis by sequentially processing text through a cascade of specialized modules. This process begins with foundational script normalization and transliteration, followed by complex phonological and morphological operations, including sandhi (euphonic combination) splitting and samāsa (compound) decomposition. It then performs exhaustive morphological parsing to identify nominal and verbal inflections, lakāra (tense/mood) identifica- tion, and culminates in high-level syntactic role labeling (kāraka analysis), providing a complete grammatical blueprint of the input text.

Unlike many previous efforts in Sanskrit computational linguistics, which have often focused

on solving isolated components such as sandhi splitting or morphological tagging in a vacuum, this work presents a truly end-to-end system. Its integrated design demonstrates how Pāṇinian grammar can be modeled computationally in a linguistically faithful manner, where the output of each module informs and constrains the next, mirroring the interdependent nature of the original sūtras. This holistic approach is crucial for resolving the ambiguities inherent in Sanskrit. Furthermore, the inclusion of sophisticated modules for voice (prayoga) detection and, uniquely, transformation (e.g., converting an active kartarī sentence to its passive karmanī equivalent) elevates the system beyond simple analysis, making it a powerful tool for both advanced linguistic research and dynamic pedagogical applications.

To maximize its utility, the pipeline generates outputs in multiple formats. A structured JSON output provides a detailed, machine-readable representation of the analysis, perfect for downstream integration into other software. Simultaneously, a human-readable tabular format presents the information clearly for scholars and students. This dual-output capability effectively bridges the gap between classical linguistic theory and modern computational ecosystems. The system's robust and modular architecture lays the necessary groundwork for the next generation of Sanskrit language technologies. For instance, the detailed

syntactic and semantic information it provides can serve as a powerful feature-rich input for neural machine translation systems, significantly improving their accuracy. It could also form the grammatical engine for sophisticated conversational agents or power intelligent grammar tutors that offer personalized, rule-based feedback to learners.

Ultimately, this pipeline embodies a true synthesis of deep linguistic scholarship and computational precision. It is an approach that respects the unparalleled grammatical rigour and generative power of Pāṇini's system, refusing to reduce the language to a set of statistical patterns. Instead, it operationalizes that very rigour, translating the abstract logic of the sūtras into concrete, executable code. In doing so, it not only creates a powerful tool for analysis but also makes the intricate, beautiful machinery of Sanskrit grammar accessible, explorable, and applicable in today's digital world, opening new avenues for research, learning, and technological innovation.

VII. FUTURE ENHANCEMENT

This research lays a strong foundational pipeline for Sanskrit text preprocessing using Paninian grammar and NLP techniques. The future scope of this work can be explored in the following directions

- Integration of Machine Learning and Deep Learning Models: Current rule-based systems can be enhanced using sequence labeling models such as Conditional Random Fields (CRFs) and BiLSTM- CRF for morphological tagging, Sandhi splitting, and Samasa recognition.
- Handling of Vedic and Poetic Sanskrit: Expand the system to include support for poetic meters (chandas), irregular compounds, and metrical distortions common in classical and Vedic literature, using pattern recognition or corpus learning methods.
- Development of a Full-Fledged Sanskrit Parser: Extend the pipeline into a syntactic parser that not only identifies morphology and karakas, but also builds a dependency tree based on Panini's sutras.
- Voice and Speech-Based Sanskrit NLP: Integrate speech recognition to convert spoken Sanskrit into structured grammatical forms for use in voice-based interfaces or educational tools.
- User-Friendly GUI and API Services: Wrap the pipeline into a web-based or mobile interface for real-time use by linguists, researchers, and students. Provide REST APIs for integration with digital Sanskrit archives or educational platforms.
- Sanskrit Grammar Teaching Tools: Embed the grammar engine into interactive tools or e-learning platforms that explain transformations like Sandhi, Samasa, Prayoga, and Lakara through visual ani- mations and examples.
- Multilingual Translation Support: With accurate Sanskrit preprocessing, develop a

robust Sanskrit- to-English or Sanskrit-to-Hindi machine translation system grounded in grammatical logic rather than statistical mapping alone.

- Corpus Expansion and Benchmarking: Create a large annotated corpus of Sanskrit sentences with labels for each NLP module (Sandhi, Samasa, Lakara, etc.) to standardize training and evaluation across future systems.
- Incorporation of Knowledge Graphs and Ontologies: Link grammatical outputs to semantic ontologies for Sanskrit, enabling deeper contextual understanding, question answering, and knowledge retrieval.
- Sanskrit Chatbot and Conversational Interfaces: Build an intelligent conversational system using this pipeline as a backend, enabling users to ask questions or converse in Sanskrit. The system can be designed to understand grammatical structures, resolve syntactic ambiguities, and generate contextually accurate responses using rule-based or hybrid generative models.

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