Computer Processing of Sanskrit

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ABSTRACT

For the computer processing of the ancient Indian language Sanskrit, which is case-based, morphological analysis is felt to be appropriate. For this analysis, the methodology described in the three major technical branches of ancient Indian sciences, viz. *Nyaya* (Logic), *Vyakarana* (Grammar) and *Mimamsa* (Vedic interpretation), is sought to be established as a suitable solution. This covers syntactic, semantic and contextual analyses of Sanskrit sentence.

The paper covers various aspects like generation, analysis and reference. Results from a prototype system built for the purpose, *DESIKA*, are reported. Words with accent marks (like Vedic text) are also dealt with in the Vedic processing module.

BACKGROUND

Ever since Rick Briggs [1,2] forcefully established the suitability and benefits of Sanskrit for Knowledge Representation and Machine translation, Paninian studies have received a shot in the arm. The conference on "Knowledge Representation and Inference in Samskritam (KRIS - 86)" held in Dec '86 at Bangalore, brought together Computer Scientists and traditional Sanskrit Scholars to discuss the subject. Further, work at IIT, Kanpur, on Machine Translation is the major initiative in applying Paninian *karaka* theory to NLP. Chaitanya *et al.* [3-5] bring out the issues involved in the machine translation between two Indian languages, with an Interlingua based on Sanskrit. Techniques like Semantic Networks [1,7,8], Conceptual Graphs [3,4], Word Expert parser [5,6], and Lexical Function Grammar [9] have been tried out. Case-based and word-expert parsing are quite suitable.

On Sanskrit processing, *per se,* some current efforts are : the 'Simurg' project, on Panini's grammar (auto-semantics) as cognitive knowledge structure [9], two-level morpho-phonology of Sanskrit [10], morphological analysis of Sanskrit by Computer [11], Paninian database, KRL based on Navya Nyaya etc [12-15] . In India, Centre for Development of Advanced Computing (C-DAC), Pune, has recently initiated work on 'Computational rendering of Panini' and 'NLP using ancient Indian Scientific approach'. This effort uses Graphics and Intelligence based Script Technology (GIST) where Sanskrit words are represented in Devanagari characters (including accent marks).

INTRODUCTION

General

Computer processing of Sanskrit could cover virtually any mode of input such as written (keyed), spoken, graphic (scanned) etc. Sanskrit also has distinct features in Vedic (sacred),

Shastric (scientific/technical) and classical literature. Further, input forms such as isolated words, sentences, text/prose, discourse, poetry, Vedic (accented) texts, aphorisms (in technical treatises), classical literature, applied areas like Medicine, Metaphysics, mathematics, Music, Arts etc. are to be handled. In what follows, we only discuss processing of written form (plain and accented) of words and sentences.

NLP and ancient Indian sciences

Artificial Intelligence research has to be necessarily multi-disciplinary in character as it involves Cognitive sciences, Computer science etc. Language comprehension requires human competences at various levels, like **Lexical, Syntactic, Semantic, Phonetic, Prosodic, Cognitive, Socio-contextual** etc. Ancient Indian scientific treatises deal with all these factors integrally, resulting in formulation of a comprehensive system of language description for correct usage. The oldest instance of such a system pertains to the Sacred (Vedic) literature dating back to many millennia, which was transmitted only orally till a few centuries ago, but is amazingly distortion-free.

This was accomplished with the devices like : a) Standard Lexicons (e.g, *Yaska*'s *Nirukta* for Vedic terms (with etymological and exegetical details) and *Amarakosha* etc. for secular literature), providing a repertoire of words; b) a well-structured grammar (e.g, *Panini*'s *Ashtadhyayi*), to generate innumerable grammatically valid word forms from a finite set of roots through rules; c) system of logical compatibility and validity rules (e.g, *Gautama*'s *Nyaya sutras*), to produce speech with meaning; d) proper phonetic classification of sounds and defined euphonic combination processes including accents (e.g, *Panini*'s *Shiksha*), for the character set of the language; e) an intonation structure of speech for communication of emotions (e.g, *Pingala*'s *Chandas sutras*), through metrics and prosody; f) a means to realise the knowledge generated in the absolute sense (e.g, *Vyasa*'s *Brahma sutras*), at philosophical level and g) guidelines for practical utility and wisdom (e.g, *Jaimini*'s *Mimamsa sutras* for Vedic usage - laukika nyayas for secular usage), in the form of axioms and moral codes of rectitude. The result of such a system is the '*Shabda bodha*' method for analysis.

LINGUISTIC ISSUES

Some Salient features of Sanskrit

A few points are worth considering here regarding the nature of Sanskrit (and most of the Indian languages).

1) All words are made of characters, either **vowels** or **consonants**. Vowels exist independently, while consonants depend on vowels. The process of *Sandhi* (euphonic combination) is defined. (Also, the character set is common).

2) Words are composed of two parts, a fixed **base** part and a variable **affix** part, both forming an integral unit. The variable part modifies the meaning of the word base, depending on a set of given relationships. Thus, the process of derivation (of declensions) is properly defined.

3) Words are of either **nominal type** or **verbal type**, i.e., denoting either entities or actions, except **particles** which are not composite in their final form. Adjectives, adverbs etc. are not independent of these.

Definition and Import of words

For determining the import of propositions, we need to consider the import of single words. A **word**, by definition, has denoting power (potency) or significance, which is the

relation of the word with an object, that always serves to revive the memory of that object whenever the word is spoken. This power is capable of denoting a particular object, the similarity of all members of its class and distinguish it from its dissimilar objects. e.g, the word 'cow', can point out a particular cow, signify that the particular cow is similar to all cows in the world and distinguish that cow from all other things such as stones, walls, trees etc. *Panini* has technically defined a word to be one with nominal or verbal terminations (1.4.14). So, the meaning is individually there for the base or root part and the suffixes.

This **potency** of words is two-fold, one **primary** or direct and the other, **secondary** or implied. Thus, the relation by which a word signifies a particular thing is by expression or implication. The first is eternal (*Jaimini Sutra* 1.1.5) and inseparable from the word. The second operates when the first is inadmissible, being derived from and dependent on it. Both these are of three types. Expressive power could be etymological (built up from the meanings of the components like root, suffix etc.), customary (gross power or meaning of the whole word without reference to parts of the word) or both (etymological and customary) partly retained. There can also be a fourth type where meaning is interpreted independently by etymology or customary sense.

Implication is the connection with the expressive sense of the word. It is resorted to when the primary sense is not applicable in the context. This could be of three types, viz. primary sense is abandoned and new one is substituted, word conveys something more in addition to primary sense or partial retention of primary sense. Rhetoric etc. may also be implied in certain situations.

Determination of word import

The import of words is learnt (in 'human cognition') in one of the following ways : Grammar, as the meaning of roots, terminations, cases etc., Analogy, of known to unknown, Dictionary, as of synonyms, descriptions etc., Express assertion of a credible person, Usage of elders, Context or Rest of the Sentence, Explanation by paraphrase or Commentary and Contiguity of well-known words. Even gestures etc. are useful.

Definition of a Sentence

We now consider what a sentence is according to various Indian systems. *Panini* has not explicitly defined a sentence although his rules cater to all factors involved when words are constituents of sentences, such as euphonic combinations, accent changes, semantic fitness while compounding words etc. *Jaimini* (2.1.46) has defined a sentence as a collection of words with a unity of sense. It gives one idea if it is a simple sentence; but if there are several sentences mutually depending on each other for their meaning, they constitute a complex sentence. Also, when the compound or co-ordinate sentences do not depend on each other for their meaning, there is a split of sentence (2.1.47). e.g, Rama came and Krishna went. Logicians opine that a sentence is a collection of words satisfying the three requisites of **expectancy, compatibility and juxtaposition**. Expectancy is the non-completion of sense (or inability of a word to convey its meaning) in the absence of some other word. Compatibility is the non-contradiction of the sense. Juxtaposition is the consecutive occurrence of words. Sometimes, the intention of the speaker is also necessary for right understanding of a sentence. This factor could be integrally considered under compatibility as well.

Sentential import

The ancient Indian approach to language analysis is based on the concept of viewing a sentence to be springing from the semantic message the speaker wishes to convey (in contrast to the phrase-structure model and the consequent binary parsing techniques for the

English-like languages). *Shabda-bodha* is the description of the comprehension in a hearer from the utterance of a sentence. This very roughly corresponds to 'paraphrase' which contains the structural description of the sentence and makes the various elements in the meaning explicit, so that the original sentence is rendered unambiguous. This when represented, can capture the disambiguated meaning of the sentence and help inferences.

Do the words in a sentence convey the meaning in isolation or as connected together? There are two different views offered by the two schools of Mimamsa regarding the function of words in a sentence. According to one view, known as '*Anvitabhidhana-vada*', words convey their own sense not in isolation but as connected together. In a sentence, no word gives by itself any clear meaning but only as related to other words. According to the other view, known as '*Abhihitanvaya-vada*', words primarily signify their own senses; but the meaning thus derived conveys the combined meaning of the sentence. We regard the first view as a sounder one. In other words, there is no necessity for apprehending each word separately before combining them in a sentence, when the meaning of the whole sentence can as well be conveyed at once as collective sense of all the words. i.e, the potency lies in the process of coherence itself, if the three previously mentioned requisites are satisfied.

Significant aspect in Sentential import

The emphasis or the significant factor in sentential import is perceived differently in the three systems and hence, the format of the paraphrase is different. The Logicians treat the Agent as central in sentence meaning, while Grammarians view the verbal meaning (activity) and Mimamsakas the efficient force (intended act) as prominent. However, there are specific situations where each of these are apt and hence, we take all these factors suitably

IMPLEMENTATION ISSUES

Computational Database:

Sanskrit is based on three fundamental units. viz. **nominal stems, verbal stems and affixes** introduced after the first two to generate additional stems as well as finished words. The *Dhatupatha* catalogues all available verbal stems, divided into ten specific classes (the *Gana patha* records groups of nominal stems which undergo specific grammatical operations). *Panini*'s methodology is to generalise nominal and verbal affixes by defining a set of archetypal affixes for these which are introduced after all stems or roots and then specifying various allomorphs for different endings and gender for nominals and for different classes and tense/mood for roots. There are 21 archetypal affixes for nominal declensions (denoted by '*sup*') and 18 for verbs (denoted by '*tin*').

Codes are devised for the ending, gender etc. for *subantas* (nouns) and for class *(gana)* usage *(padi),* transitivity, accent etc. for tingantas (verbs). A nominal lexicon is then chosen, to cover all the allomorphic forms. Thus, updating the lexicon can be done in a categorised manner. The *dhatupatha* is codified as the verbal root lexicon. A list of the various *avyayas* (indeclinables) with codes is used for particles. The codified suffix database is prepared for nouns and verbs covering all the allomorphic forms (of archetypal *sup* and *tin* suffixes).

Syntactic analysis

Here, we identify all the words in the sentence individually in terms of the grammatically valid formations ('*ab-ultimo*' analysis). For this, we analyse words based on terminations or suffixes and bases or roots. This utilises the mapping of archetypal suffixes to the allomorphic forms. Santhi Seela *et al* [16] have used a similar method, in the context of Indian languages. Kanthan [17] has discussed the types of *Ashtadhyayi* rules for generation of word forms. Katre [18] has described these mappings. The steps involved are :

1) Split the word at its valid breakpoints (vowels and consonants). Splitting of *Sandhi* is also carried out, where applicable.

2) Combine the split parts into LHS and RHS iteratively.

3) Carryout string matching with appropriate databases to identify all valid grammatical combinations.

Semantic Analysis

As per Panini's *Karaka* theory, there are six functors, viz. **Agent** (5 types as independent doer, causative agent, object-agent (reflexive), expressed and unexpressed), **Object** (7 types as accomplished, evolved, attained, desired, undesired, desired-undesired and agent-object), **Instrument** (2 types as internal and external), **Recipient** or beneficiary (3 types as impelled, assenting and non-refusing object), **Reference** while separating (2 types as static and mobile) and **Locus** or substratum (4 types as pervasive, contiguous, subject or object and proximate). (The functor sub-types are empirically listed in '*Shabda Ratnavali*', an illustrative work on elementary Sanskrit grammar). These have correspondence with cases. Each activity has definite mandatory, optional and inhibitory functors. After syntactic analysis, word-by-word semantic analysis begins with the verb. Using the *Vibhakti-Karaka* mappings, we list the possible context-free functional roles for each word. Then, by employing compatibility criteria we determine the karakas at the sentence level and explain the meaning through paraphrasing or change of voice etc.

Meaning Representation

How to represent meaning (or Knowledge, in general) in the computer? This is the crux of the whole exercise and we describe the ancient Indian method in this regard. This is necessarily empirical in nature. We develop a classification scheme for all substances in a structured form (Ontology) to explain meanings and facilitate 'machine understanding'.

CONCEPTUAL ISSUES

Fundamental Metaphysical categories

All knowable things are divided into *Pramana* (Means of valid knowledge) and *Prameya* (Object of knowledge). There are three *pramanas*, viz. **Perception, Inference and Verbal testimony**, and these include comparison, presumption, non-apprehension etc. suitably. Perception is knowledge generated by the direct contact of sense organs with objects. Inference is the knowledge of probandum based on probans established by logical concomitance. Verbal knowledge is the one arising from spoken words or verbal statements through the comprehension of the connected meaning. Perception and Verbal testimony can be stored as facts and inference as if-then rules in the machine.

Prameyas are classified under two broad headings as **substance and non-substance.** Substance is defined as having states (or substratum for modifications). This is of two classes as material and non-material (spiritual). Cosmic matter and time are material substances. Spiritual substances could further be self-revealed or revealed to others. Sentient beings are self-revealed.

Non-substance is defined as one which cannot be substratum to something else. It should be integrally (inseparably) related to a substance and not admit conjunction with another quality. There are ten basic metaphysical attributes, viz. sattva, rajas and tamas - representing whatever is fine or light, whatever is active and whatever is heavy - the three attributes of Cosmic matter; sound, touch, colour, taste and odour - the five attributes of gross elements;

conjunction and potency. These cover the innumerable other qualities belonging to substances in conformity with the *pramanas*. Potency is the special property of a causal substance by virtue of which, it brings out the necessary effect. Conjunction is a form of relation which holds between two physical objects.

Substance and attribute are distinct but integrally (inseparably) related. There are two types of entities in the Universe as those that are separable and those which are not. In the former case, the relation is conjunction, which is external, ceasing to exist the moment the objects are separated. In the latter case, we conceive a unique inherent or internal relation, which is the very nature of the relata lasting as long as the relata exist. Cause and effect are different states of one and the same substance. In terms of these, we define all things in the Universe. This classification is based on Tattva mukta kalapa of Vedantha Desika, a Logician-philosopher of 13th century A.D. [19].

PRACTICAL ISSUES

According to Indian systems, word meanings can be represented in terms of the 'essential' (or definitive) characteristics and additional (or substantive) features. The former is for distinguishing an entity from dissimilar entities while the latter is to specify amongst similar entities. Nouns are associated with their generic properties and specific features. For substantives, modifiers etc. parameters of modification is specified. Here, help is available from *Amarakosha*, wherein a list of adjectives is given. Some of these are indeclinables. [20] describes the various fields a word-expert may contain.

Now, how do we use these? One way is to list out the characteristics of conceptual entities. Substances have features like name, form, meaning (conceptual type), attributes (physical, mental, ethical etc.) and source of knowledge through which they are known etc. Thus, a physical thing could be defined by the attribute of form as being of a certain colour(s), shape, size etc. Form is known through ocular sense when light is there etc. Thus, for an activity like 'seeing', the primary sense requires an object having a perceptible form, the agent to be sentient with ocular sense intact, presence of light, absence of obstruction, sense contact etc. Similar descriptions are to be defined for the basic activity categories.

For this, we propose a method of analysis based on **activity categorisation**. Here, we analyse *Panini*'s *Dhatupatha* on the basis of the root meanings and arrive at distinct activity classes. There are 2000 roots describing over 600 activities or states. Grouping similar activities, we arrive at about 50 'categories' of accomplishment and state types. This grouping is based on transitivity, multiple senses, voice, mode (verbal, causative, desiderative, intensive, frequentative or reflexive), preverbs, accent, derivatives (krdantas) etc.

This categorisation applied for the six functors mentioned earlier reduces the number of dintinct activity types. For example, prevailing and humbling are two senses of the root '*ji*'. Here, the first meaning could be intransitive while the second is clearly transitive. There is a list of intransitive actions (or states) like growing, decaying, fearing, living, dying, shying, existing (or being), standing, keeping awake, sleeping, playing (sporting), liking, glowing (or shining) and their synonymous ones.

Similarly, in Sanskrit, there are 16 ditransitive activities (terms in brackets denote typical object or goal) such as milking (cow, milk), begging (donor, something), cooking (rice, bath), punishing (guilty, penalty), obstructing (confined, place), asking (someone, query), gathering (fruit, tree), speaking (hearer, topic), instructing (someone, order), conquering (loser, stake), churning (input, output), stealing (victim, item) and leading, carrying, drawing or dragging (thing, place). Activities other than intransitive and ditransitive ones are transitive.

As an illustration, let us consider an activity like 'going', which could be transitive or intransitive. All activities mandatorily need an agent. The type of the agent differs between activities, e.g, 'going' could take a sentient or non-sentient being as agent. In the former case, the literal meaning is always applicable, while in the latter, it is not necessarily the case, as e.g, when a vehicle ('automobile') is said to go, as the meaning needs modification. The background knowledge a human being possesses can be captured by defining the agent as non-sentient which necessitates taking recourse to such modification in meanings. In fact, sentient beings are defined to have the essential (distinguishing from non-sentient) characteristic of 'agency' to know, to desire, to act and to enjoy the fruit of action (pleasure or pain) etc. Further, the process of evolution and creation as given in ancient Indian sciences provide proper generic and specific grouping labels for noun classification. Spiritual category is needed to describe natural acts like rain, thunder, lightning, wildfires etc. or supersensory things like self, e.g, to understand sentences like 'I know myself' or 'he knows that he knows'.

Thus, activity categories are defined in terms of the functor and their type requirement, besides activity content in terms of accomplishment, sub-action, event, state etc. From these activity categories, we get the demand words for noun classification (to specify the functors). Indeclinables, substantives etc. are also derived based on semantic functions. Compilation of sample sentences also throws up relevant category labels. The functor requirement denotes expectancy while in a sentence. The type check of the candidate words with activity characteristics ensures compatibility and context relation.

Heuristic rules are devised to resolve cases where no verb, more than one verb or non-functor words are present. These derive mainly from 'laukika nyayas', which are akin to formulation of common sense. Besides, *Mimamsa* also has clearly defined criteria for relative priority among various means of knowledge like, express mention, word meaning (explicit indication), syntactic connection, context (commencement, conclusion, emphasis, novelty, purpose and propriety), relative position and name.

DESCRIPTION OF DESIKA

We now report on our efforts, with the description of the system, *DESIKA*. [21] gives fuller details.

Introduction

The main function here is to take an input sentence in Sanskrit and get its paraphrased meaning as output in Sanskrit itself. The grammar rules are the basis of syntactic and semantic analyses. The logical compatibility criteria and conceptual classes are derived from the *Nyaya* system and certain criteria for contextual disambiguation are taken from *Mimamsa* system.

Regarding databases, a nominal lexicon with about 3200 words, taken from *Amarakosha* and *Panini*'s *Linganushasana*, a verbal root dictionary covering the Paninian *Dhatupatha* and a list of indeclinables and nominal & verbal suffixes have been prepared. Compilation of sample sentences with their characteristics as relevent to *Shabda bodha* has begun.

All nominal declension types are covered under Nouns (*Subanta)* generation and all modes and voices for the verbal roots listed in *Panini*'s *Dhathupatha* are covered in the Verbs (*Tinganta*) generation. These modules so far cover about 400 rules of Ashtadhyayi.

Why Sanskrit ?

Reasons for choosing Sanskrit are :

1. Richness of scientific literature with in-depth and exhaustive analysis.

2. Systematic approach meant for cognitive knowledge description.

3. Extendability to other Indian languages (and Pali &Prakrit).

4. The phonetic basis of the language being useful for Speech analysis as well.

Objectives - linguistic :

'Understanding' a natural language input (e.g, an isolated sentence) by :

1. Paraphrasing, changing the voice, synonymous explanation, description, or in a "classical format", termed as "Shabda-bodha".

2. Answering queries involving Inference, Connection, Reference etc.

3. Summarising by picking the key thoughts in the input sentences.

- computational:

1. Developing custom-made tools for NLP, creation of Dictionary, Thesaurus, Concordance etc, creation of function and data libraries in standard formats.

2. Developing a language independent knowledge representation scheme based on Ancient Indian Scientific works.

3. Design of a **'Linguistic Work Station'** aimed at helping language research through computers.

Functional modules

There are separate modules for the three functions of the system, ie., Generation, Analysis and Reference. Generation of Nominal or Verbal class of words is carried out by the user specifying the word and the applicable rules being activated. Outputs are in standard (conventional) format. In Analysis, the syntactic identification and assignment of functional roles for every word is carried out using the *karaka - vibhakti* **mappings.** Compatibility criteria are applied for sense disambiguation. The output can be had as voice change or paraphrasing in one of three formats mentioned earlier. In the Reference module, a complete 'trace' of the process of generation or analysis is planned to be provided, besides information/help. This module is still in the initial stages.

The system can also accept accented input like a Vedic hymn, for example. During syntactic and semantic analyses, the accent meanings are considered. We are currently preparing the samasa and sandhi parsing modules wherein we can demonstrate the advantages of knowing the accent for precise sense determination. [22] deals with some aspects of Vedic processing.

Examples

A sentence like रामः वनम् गच्छति ('Rama goes to the forest') will be analysed as under:

After syntactic analysis, we get two identifications each for all the three words; रामः - as noun, masculine, nominative, singular (राम as base) and as verb, meaning 'to give', active voice, adadi gana, present tense, parasmai padi, first person, plural (रा as root); वनम् - as noun, neutral gender, nominative and accusative, singular (वन as base) and गच्छति - as noun, masculine (and neutral), locative, singular (गच्छत् as base) and as verb, meaning 'to go', active voice, bhvadi gana, present tense, parasmai padi, third person, singular (गम् as root).

Thus, the first and the last words can have one of the two roles of verb and noun. The

4. Dr Rajeev Sangal and Dr Vineet Chaitanya [1986], "An intermediate language for Machine Translation : An approach based on Sanskrit using Conceptual Graph notation", Computer Science and Informatics, Jour. of Comp. Soc. of India, 17, 1, pp. 9 -21, 1987.

5. Dr R.M.K. Sinha [1989], "A Sanskrit based Word Expert model for Machine Translation among Indian languages", Proc. of Regional Workshop on Computer Processing of Asian Languages (CPAL), 1989, pp.82-89.

6. Akshar Bharati, Vineet chaitanya and Rajeev Sangal [1989], "A Karaka based approach to Parsing of Indian languages", TRCS-89-88, I.I.T, Kanpur.

7. S.N.Srihari, W.J.Rapaport and D.Kumar [1987], "On Knowledge Representation using Semantic Networks and Sanskrit", Tech. Rep. 87-03 of SUNY at Buffalo, USA.

8. Prof. Subhash C. Kak [1987], "The Paninian approach to Natural Language Processing", Intnl. J. of Approximate Reasoning 1987, 1: 117-130.

9. Dr E. Schredl [1990], "Sanskrit Computational", ['simurg' project], Germany.

10. J. Ahlfors [1990], "Two level morphophonology of Sanskrit", Helsinki, Finland.

11. A.Verboom [1990], "Morphological analysis of Sanskrit by Computer", Netherlands.

12. George Cardona [1990], "Paninian Database as information Archives for Sanskrit grammar", M.I.T, USA.

13. Anand V Hudli [1990], "A KRL based on Navya Nyaya", Purdue Univ, USA.

14. S.C. Bhatnagar [1990], "Programming languages and Sanskrit", Univ. of Nevada, USA.

15. P.S. Filliozat [1991], "Computer-aided research on Panini", Paris, France.

16. R. Santhi Seela and G. Krishna [1990], "Analysis of case-endings in Indian languages and bidirectional machine translation between Indian languages and English", J. Indian Inst. Sci., Mar-Apr. 1990, 70, 131-143.

17. K.L.Kanthan [1989], "Formal Language System of Panini", Pre-Conference Papers of National Conference on 'Samskritam and Computers', New Delhi, 1989.

18. S.M.Katre [1989], "Ashtadhyayi of Panini", Motilal Banarsidoss.

19. S.M. Srinivasa Chari [1987], "Fundamentals of Vishishtadvaita Vedanta : A study based on Vedanta Desika's Tattva-mukta-kalapa", Motilal Banarsidoss.

20. P.Ramanujan [1990], "A scheme for knowledge representation in Samskritam", paper for Abhinava Vidya Bharati, USA awards, 1991.

21. B. Sabarinath and Saji K. David [1991], "Natural Language Understanding System for Sanskrit", M.Sc. (Comp. Sc.) Thesis, Univ. of Kerala, 1991.

22. P. Ramanujan [1992], "Computerisation of Vedic texts", Proc. of National Conference on Vedas and Shastras, Tirupati.

23. P. Ramanujan [1992], "मस्तिष्क यन्त्रे शाब्द बोध प्रतिरूपणम्", Proc. of National Conference on Vedas and Shastras, Tirupati.