

# Pāṇinian Phonological Changes: Computation and Development of Online Access System

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## Abstract

Pāṇini used the term *saṃhitā* for phonological changes. Any Sound change which alters phonemes in a particular language is called Phonological Change. It arises when two sounds are pronounced in a language with uninterrupted speed, then those letters are affected by each other due to Articulatory, Acoustic and Auditory principles in language. The pronunciation of two sounds that are in extreme proximity, affects each other and changes them. In simple words, this phenomenon is known as sandhi. Sanskrit is considered one of the oldest languages in the world. It has produced one of the most huge literary text corpora in the world. The tradition of Sanskrit began in the Vedic period. Pāṇini's *Aṣṭādhyāyī* (AD) is a complete grammar of Sanskrit. It also covers Sanskrit sounds and phonology. Phonological changes are a natural phenomenon in any language during speech but in Sanskrit, it is highly reflected. Sanskrit corpora contain numerous long words. It looks like a single sentence due to sandhi between multiple words. The process of phonological changes occurred based on certain rules of pronunciation and it is codified by the Pāṇini in AD. Pāṇini has codified these rules systemically but the computation of these rules is a challenging task. Therefore, the objective of the paper is to compute the rules and demonstrate an online access system for Sanskrit sandhi. The system also generates the whole process of phonological changes based on Pāṇinian Rules. It also plays a very effective role in Digital classroom teaching, boosting teaching skills and the learning process.

**Keywords :** Phonological Changes, Computation and Development of Online Access, Sandhi, Pāṇinian, *Aṣṭādhyāyī* (AD), Digital classroom teaching, Sanskrit Grammar, Derivational Process etc.

## 1. Background

The most prominent feature of ancient Indian linguistic culture was its concern for maintaining the accuracy of the spoken word. It was speech, spoken word, and not written letters based on Sanskrit grammar. The spoken language is considered the basis of the actual Sanskrit language. All speculations and practices are concerned with the oral methodology. Sanskrit is a compounding, morphologically and phonetically strong language. Sanskrit texts contain numerous words which are composed by the combination of two or more words using the last letter from the first word and the first letter from the second word. The last letter of the first word and the first letter of the second word sometimes change during the pronunciations. This process is generally known as Phonological Changes. Any sound change which alters the number or distribution of phonemes in a particular language is called Phonological Change. Because whenever two letters are pronounced in a language with uninterrupted speed, then those letters are affected by each other. These two letters or sounds may merge to give a single sound, one of the two sounds may get changed or reduplicated before combining with the other, or even get elided. A new sound may also be appended in between. This linguistic variation is reckoned as Phonetic Change or Sandhi. Sound Changes in Pronunciation are majorly due to the frequency of words which are motivated by physiological factors. Sound change takes place due to Articulatory, Acoustic and Auditory principles in language. The pronunciation of two sounds that are in extreme proximity, affects each other and changes them. These variations are known in Sanskrit as Sandhi. Sandhi refers to “put together”. Sandhi is the coalescence of two letters in immediate contact. It means when two sounds combine, they influence each other's sound structure, resulting in different variant pronunciations for these sounds. Sandhi word is itself made up of two components “*sam + dhi*”. *Sam* means “together” and *dhi* refers to “placement or location”. It is conjoined to

depict the meaning of place together or merged. Sandhi takes place according to certain rules codified by the Pāṇini and are explained formally in his grammar known as *Aṣṭādhyāyī* (AD). Pāṇini's AD is also based on the sound of Spoken Sanskrit. But the word Sandhi does not appear in any of the AD *sūtras* (Bhardwaj, Gantayat, Chaturvedi, Garg, & Agarwal, 2018). There are certain *sūtras* that are governed by a condition known as *saṃhitā* which as defined in *sūtra* “*paraḥ sannikarṣaḥ saṃhitā*” (1.4.109) means “closest proximity of letters”. These *sūtras* talk about the changes that occur when two letters are in “immediate proximity”. The process of Sandhi is fundamental to the Sanskrit language as it enables the formation of new and more complex words using simple words. Any computational tool for processing Sanskrit must to be able to merge words according to the rules of Sandhi. The accuracy of any such tool critically depends on the eradication of errors in the Sandhi processing. The AD is formulated in a morphologically, syntactically and lexically regimented form of Sanskrit (Kiparsky, 1995). AD includes generative phonology of a depth and exhaustiveness to which no modern generative phonology has even come close, which is moreover integrated with a fully panned out generative syntax and morphology, in a system of 4000 formalized rules based on very specific and elaborate principles of Sanskrit linguistic description (Joshi & Kiparsky, 1977). NASA scientist Rick Briggs (1985) has attracted public attention to his artificial intelligence research and has accepted the techniques used to present knowledge to the methods used in the implementation of rules used in Pāṇinian grammar (Chandra, 2021). In modern grammar, Pāṇinian grammar is comprehensive, scientific, and organized equivalent to working of a computer program. Nevertheless, despite the vast literature on the Sanskrit language, the amount of digital medium of Sanskrit is scanty in comparison to other language literature. In the field of Sanskrit research, constantly state-of-the-art techniques and tools are being developed which are helpful in e-learning. In order to fulfill this goal, the

*Pāṇinian* rule and example-based hybrid approach is adopted to create the online access system.

## 2. Problem, Solution and Objective

Along with the progress, and changes in information technology, society has had a profound impact on the education system. It provides an opportunity to develop new flexible learning an environment that was not possible before. In the age of digitalization and technology, the Sanskrit field is engrossed in a conflicting sphere where Sanskrit language and literature have gigantic literary corpora but we have an extreme scarcity of Sanskrit electronic tools to aid the teaching and learning process of Sanskrit texts. So that this Indian knowledge tradition is available online in digital form and is accessible to all the enthusiasts. Presently, it is part of the curriculum of all major Indian universities and affiliated colleges conducting Sanskrit courses and teaching grammar topics based on *Siddhāntakaumudī* or *Laghusiddhāntakaumudī*. Also, Sandhi and its Derivational Process is a part of the *Vyakaranasiddhāntakaumudī* and *Laghusiddhāntakaumudī* but there is no such digital medium or any tools available which discuss the derivations in detail. The development of any such digital online process would aid learners in garnering knowledge of the Sanskrit Sandhi derivational process. Although there are a handful of tools available that does the task of sandhi in capacious to depicting the entire derivational process. Also, Sanskrit has *kādambarī*, *vāsavadattā* etc. text there are huge uses of sandhi padas having enormous sandhi terms which appear to be like a whole sentence. To grasp the content and have an informed understanding of this linguistically advanced text, it is necessary that researchers, laureates, and scholars develop the grammatical skills of sandhi. But the lack of efficient tools harms the learning process and therefore, the progress is also much dilated.

The only solution to the aforementioned problems is to build an electronic system for the Sanskrit Sandhi Siddhi process. With the help of tools, learners will easily access to learn sandhi and understand Sanskrit text.

Therefore, the main objective of this paper is to develop a web-based system for e-learning by computing *Pāṇini's* Phonological rules. Thus, we discuss a structure for computer representation of the *Pāṇinian* Phonological Changes in Sanskrit grammar. Sandhi tool is an easy as well as an interesting medium that renders an entirely new dimension in the field of Education, Speech Technology and adds unique prospects to the traditional approach of Sanskrit Teachings. As result, it will boost the teaching skills and the learning process. This tool will prove very helpful for those who wish to grasp Sandhi in grammatical tradition. Simultaneously, other topics of Sanskrit can also be made easily comprehensible with the help of this tool.

## 3. Phonological Changes in Sanskrit

Phonetic change occurs when two sounds in proximity are pronounced and make changes. In this process, internal and external oral factors of the mouth affect the pronunciation of sounds. In AD (दीक्षित, 2016) Pāṇini used the word *Samhitā* (परः सन्निकर्षः संहिता-1.4.109) to depict phonological changes. There are three possible potential combinations leading to the formation of sandhi such as; *svara* sandhi, *vyañjana* sandhi and *visarga* sandhi. When a vowel affects the second vowel and changes it to another

sound, called *svara* sandhi. Similarly, a consonant followed by a consonant is defined as *vyañjana* sandhi (*saṃhitā*) and the combination of a vowel and visarga followed by a vowel or consonant is called *visarga* sandhi (*saṃhitā*). *Pāṇini* uses the term *saṃhitā* only to connote the vowel-vowel combinations (Zwicky and Arnold, 1965). Other rules are just called consonant-consonant changes. Visarga sandhi elucidated under *Pāṇini's* AD is nothing but changes associated with a final or in a word and is grouped by *Pāṇini* with other consonant changes. *Visarga* rules are generally expressed as changes that occur when a particular vowel or group of vowels is followed by *visarga* which in turn is followed by various letters. The internal sandhi and external sandhi are other useful classifications are also done by the scholars. Internal Sandhi refers to the sandhi amongst case endings, verbal affixes, prefixes and suffixes which results in the formation of a word as *saṃ + kṛita = saṃskṛita*. External Sandhi is what occurs between words, whether they form a compound or not (Chakraborty, 2021) as *sūrya + udayam = sūryodayam*. Due to this classification, sandhi has five types: *svara* sandhi, *prakṛtibhāva* sandhi, *vyañjana* sandhi, *visarga* sandhi, *svādi* sandhi (आचार्य, 2019). These are not additional sandhi but the incorporation of major *sandhis*. *Prakṛtibhāva* sandhi is part of *svara* sandhi and *svādi* sandhi is a part of visarga sandhi. These additional types are due to internal and external conditions of sandhi. Thus, Sandhi is mainly three types.

## 4. Digital Access and Sanskrit Sandhi

Information technology affects all aspects of human activities and therefore, exerts a similar influence in the education sector as well. When a learner is able to take responsibility for their own learning, it would result in an increased demand for education and magnify the need for more digital learning equipment and e-tools. E-learning is commonly referred to as the intentional use of networked information and communications technology in teaching and learning. Digital Access for education and learning can be described as using a digital medium or electronic media and technologies such as the internet, intranet, extranet, satellite broadcasts, audio/videotape, interactive television and video-conferencing, to delivery instructional content and to create, foster and facilitate learning experiences. In contemporary times, when globalization and the sector of information technology are at their peak, the entire world is connected by a click of a button, the global news is generated and exchanged through web mediums, yet, any instant e-learning system for important grammatical content such as *sandhi*, *subanta*, *tiṅanta*, *ṛdanta*, *samāsa* etc are unavailable to the digital world.

Sandhi as previously discussed is an eminent topic of Sanskrit linguistics and a part of major curriculum content in every university having a linguistics and Indic department. The system being deliberated in this research paper is a digital platform enduring the potential for global access to the derivational process of sandhi along with its exegesis and detailed description.

Sanskrit Sandhi is an issue on which almost all the institutions working on computational linguistics in Sanskrit and other primitive languages are continuously performing research and making significant advancements. The most prominent of these institutions are The Computational Linguistics R&D at the School of Sanskrit

and Indic Studies (J.N.U), Department of Sanskrit, University of Hyderabad and Technology Development for Indian Languages (TDIL, 2021). These institutes have continuously created computational tools by performing various researches on the basis of Computational Sanskrit. Along with many tools manufactured by these institutes, two sandhi-related tools- Sandhi Generator and Sandhi splitter are also available. Both the systems developed by Jawaharlal Nehru University are based on *Laghusiddhāntakaumudī*. Sandhi Generator System (Mishra & Jha, 2009) makes a Sandhi between two *padas* or *varnas* on the basis of Panini's Sandhi rule. And Sandhi Splitter System (Kumar and Jha 2007) identifies the syntactic term given in the input form and makes a possible break of it and also presents the sandhi *sūtra*, on the basis of which the Sandhi term is formed. Department of Sanskrit (UOH) Under the guidance of Prof. Amba Kulkarni (Kulkarni 2021), two tools related to the Sandhi- *sandhi* and *sandhi-vicchedikā* are based on *Vayakaranasiddhāntakaumudī*. The first tool treats on the basis of input in the form of two words. And the second Sandhi breaks the word. The department declares 96%-98% fair results of these sandhi tools. Similarly, Sandhi and Sandhi splitter tools have also been manufactured by Technology Development for Indian Languages (TDIL). This system also presents its AD sequence along with the Sandhi *Sūtra*. Many Sanskrit tools are available on the portal ([www.sanskritworld.in](http://www.sanskritworld.in)) a web portal for Computational Sanskrit created by Dr. Dhaval Patel (2022). There is also a sandhi tool in Tools. Input form for Sandhi, this tool by taking *pada + pada* or *prātipadika + pada* and identifying the Sandhi on the basis of input presents Sandhi form, Sandhi *sūtra*, *vārtika* and their work, AD's *sūtra*. The Sandhi splitter system is being manufactured by the Karnataka Sanskrit University. This system was developed by Amba Kulkarni (Sanskrit Studies Department, University of Hyderabad), P. Ramanuja (Karnataka *saṃskṛta* University) and Nicolas Reimen, Karnataka *saṃskṛta* University. The system is currently under development. This work is being developed to split the Sandhi. A Sandhikosh: A Benchmark Corpus for Evaluating Sanskrit Sandhi Tools has been developed by the Indian Institute of Technology, Delhi and IBM Research in collaboration with Shubham Bhardwaj and his colleagues (2018) in which five different departments- *aṣṭādhyāyī* Corpus, *Bhagavad\_Gita* by making Corpus, Rule-based Corpus and Literature Corpus, UoH Corpus, data collection of about 14000 Sandhi words has been made. Under the guidance of Pro. Gérard Hute (2013), the INRIA (French Institute for Research in Computer Science and Automation) developed the sandhi tool called the Sandhi Engine. It is the only system in the systems of the Sandhi that explains the internal and external distinction between the Sandhi. Similarly, on another website, Green Message: The Evergreen Messages of Spirituality, Sanskrit and Nature (Message 2021), there are two systems for Sanskrit Sandhi, Sanskrit Sandhi Rules and Sanskrit Sandhi Tool. The first system presents three options to the user, vowel, consonant, and visarga. This system exhibits the collection of disparate Sandhi rules and presents an example-based Sandhi between whichever characters is favored. It further elucidates the Sanskrit Sandhi Tool gives the dissection, i.e on giving two different terms, Sandhi, the name of the Sandhi and the Sandhi Rules by identifying the Sandhi in the result. Sanskrit Dictionary (2022) website has

prepared some online tools. In which there is a Sanskrit Sandhi Calculator and a Sandhi Game called '*Sandhi Invaders*'. This calculator accepts two characters or words as input. by identifying the inputs like syllables, syllable positions, changed characters, and the rule by which the Sandhi is It has happened, presents that AD *Sūtra*. The '*Sandhi Invaders*' is a typing game, in which 572 Sandhi rules have been arranged in a particular order. It's a simple and interesting way to learn facts of the sandhi generation. In this sequence, many computer tools have been developed in the field of Computational Linguistics since 2014 by the Department of Sanskrit, University of Delhi. *Sasūtra* Sandhi Generator related to Sanskrit Sandhi was built by this department which works with the perfect example and rule method and it is the only system of sandhi that presents the complete derivational process along with making the sandhi.

## 5. Computation Process of Pāṇinian Rules for Sandhi

*Pāṇini* has encoded the rules in AD and presented them very briefly just like in a computer program the data is different. A relatively small part of these underlying principles is described in the rules of *Pāṇini* AD. To understand them, first of all, we have to decode these rules. These rules can be computed very easily. The *śivasūtras*, enumerate a catalog of sounds (*varṇasamāmnāya*) in fourteen classes. *Pāṇini* uses abbreviatory labels termed *pratyahara* to describe phonological classes. This *pratyahara* are interpreted in the context of an ancillary text of the AD (Malcolm, 2007). For example- If we take the formula '*iko yaṇaci*' (इको यणचि- 6.1.77) (आचार्य, 2019) for the sandhi of *yaṇ*. To understand this formula, first of all, the passage (separate each of the words) is done. By separating, we get a total of three words *ikaḥ*, *yaṇ* and *aci*. Now division is seen in this these words *ikaḥ* has the sixth declension (*vibhakti*), the *yaṇ* has the first *vibhakti* and *Achi* has the seventh *vibhakti*. In order to understand the meaning of these words, *Pāṇini* has given the rules that the word in which the sixth declension will be there, the word with the first declension will be in its place, and the word with the seventh declension will be after (*nimitta*). In this way the general meaning of this *sūtra* is - In place of *ik*, there will be *yaṇ* after *ac*. Now these three words are *ik*, *yaṇ* and *ac* technical words, to understand this we have to go to the sound module of *Pāṇini*'s AD. This will give us the detail of all these three technical terms. *ik* to *i/ī*, *u/ū*, *r/ṛ*, *l/ḷ* and *yaṇ* to *y*, *v*, *r*, *l* and *ac* to *a/ā*, *i/ī*, *u/ū*, *r/ṛ*, *l/ḷ*, *e*, *o*, *ai*, *au*. There is a sense of letters like *ai*, *au* (all vowels) etc. There is also an exception to this *sūtra*, there will be a long sandhi in the same tone. In this way, the meaning of this *sūtra* is *i/ī*, *u/ū*, *r/ṛ*, *l/ḷ* after any dissimilar vowel, then *y* (य) in place of *i/ī*, *v*, (व) in place of *u/ū*, *r* (र) in place of *r/ṛ* and in place of *l/ḷ*, the order becomes *l* (ल). This process is easy to compute. Its format can be seen in Table no-1.

| SR | Rec Nn. | End w1 | Start w2 | Rem W1 | Rem W2 | Addstr  |
|----|---------|--------|----------|--------|--------|---------|
| 1  | 1       | इ (i)  | अ (ā)    | इ (i)  | अ (a)  | य (ya)  |
| 2  | 1       | इ (i)  | आ (ā)    | इ (i)  | आ (ā)  | या (yā) |

|   |   |          |          |       |          |            |
|---|---|----------|----------|-------|----------|------------|
| ३ | १ | इ<br>(i) | उ<br>(u) | इ (i) | उ<br>(u) | यु<br>(yu) |
|---|---|----------|----------|-------|----------|------------|

Table 1: Computational Rules for Sandhi Recognition and Analysis

The rules database and AD *Sūtrapath* database for the *Rupasiddhi* process have been created in a specific format. In this way, the Sandhi *Sūtras* have been computed using the method given by *Pāṇini*.

## 6. Used Research Methodology

The basis of the computational rules is the sandhi *prakaraṇa* analyzed in the *Vyakaranasiddhāntakaumudī*. This system was developed on the basis of about 131 Sandhi *Sūtras* and 39 *vārtikas* of *kātyāyana* related to the sandhi. It has been developed on the basis of the Rule and the Example-Based Hybrid Approach. For the general procedure, the formulas are kept under the example method and in special cases, the formulas are kept under the rule method.

Rules and examples in two databases have been created to identify the sandhi. There are total of 4194 computational rules have been kept in the computational format by expanding the *Pāṇinian* rules related to the Sandhi. From this database, the identification of the sandhi between two characters, the analysis and the sandhi is done.

*Pāṇini's* rule and example-based hybrid method have been used in the development of web-based computing systems for the sandhi. Just as *Pāṇini* has presented two types of rules in his AD, which are called General Rules and Exceptional Rules. Similarly, in this system also the sandhi is obtained with the help of a rule-based method for general rules and an example database for exceptions. Simultaneously, computational linguistics and web technology methods have been used. The Research Methodology can be understood in figure 1.

## 7. Computational Platform and Techniques

This sandhi system is Web based system. There are mainly two main components to develop any Web based system- first front end and second back end. Front-end can be said to be all the visible aspects of the website that the user can see and experience. In technical language, the term 'client-side' is used for the front-end. The front end mainly consists of web pages. For this system, we used an HTML page, and code of CSS and JavaScript have been included in the HTML code to make it attractive and useful. Back-end is where all work is done in the background. It makes all decisions about how and when to present the information. The programming language Python has been used for web development. The Python-supported Flask server is used for the server and the MySQL database and text files have been used for the database.

## 8. Components of the System

There are mainly three components in this system-

- The first component identifies the sandhi on the basis of user provided terms and makes a Sandhi.

- On the basis of the second identity, codified changes of sandhi.
- On the basis of the third sandhi, it shows the complete Derivational process of making a sandhi word with the *Pāṇini's Sūtras* and *kātyāyana's vārtikas*.

This can be understood through figure no-1.

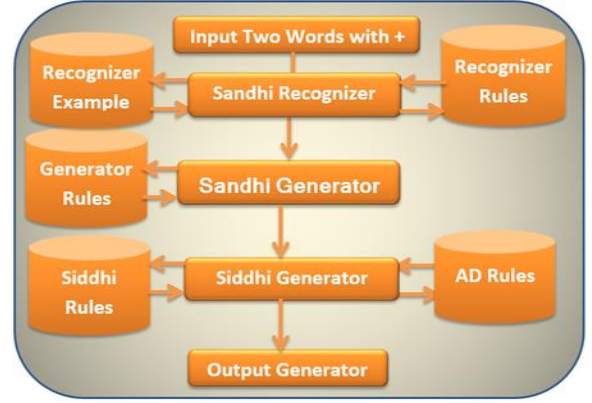


Figure 1: Diagram of the system.

The first webpage of this system is the user interface. The user interface is the point through which a user interacts with a computer, website, or application. The user interface of the presented system is developed in HTML with the help of a Form-based user interface. When submitted by the user by entering his input in Devanagari Unicode (two words with “+” sign) in a text area available in the interface. So that given gets refined and comes to the component called Sandhi Identifier. This component identifies the sandhi with the help of base sandhi identification rules based on the given input. After that, on the basis of the identification, the Sandhi Generator module does the work with the help of rules and an example database and generates a code for the accomplishment process, and sends it to the next step. The Sandhi Siddhi Generator module generates the Siddhi codes from the code obtained from the Sandhi Generator with the help of the *rūpasiddhi* database. Again, this siddhi code is sent to the AD database, where *Pāṇini* converts the code from the rules and communicates it to the output generator. The Output Generator converts the string obtained from the previous element i.e Sandhi Siddhi Generator into text. After that, by creating an automatic table, replaces that text in its rows and columns. As a result, all the information about the derivational process is displayed to the user in the same webpage result.

## 9. Result and Discussion

With the help of this interface, the user can type any two words in Unicode incorporating a “+” sign between them in Devanagari and click on the submit button for *sasūtrasandhi*. The result is generated on the webpage on the basis of the input provided in UTF-8 in Devanagari script, the Derivational process of sandhi is displayed on a webpage in tabular form. In the result obtained, each *sūtras* and *vārtikas* used in the process of sandhi are hyperlinked. On which, when the cursor is moved, the meaning of that *sūtras* and *vārtikas*, its complete explanation appears on a new webpage. This system is a completely user-friendly system and is easy to use. Through the use of this system, any student can easily use it in his studies and faculties in

their teaching pedagogies. This web-based system is completely dependent on the rules of the procedure discussed in the *Vayakaranasiddhāntakaumudī*.

This system can be easily accessed anywhere at the user's convenience with the use of the internet. In the Sandhi system, no dictionary has been used for the Siddhi process, but the basis of the entire Siddhi process is examples and rules and methods. By looking at the position of the sandhi, this system identifies the automatic sandhi in a few moments and at the same time, it also verifies how many sandhi forms are formed in the case of a particular sandhi. On the basis of the given input, this system automatically analyzes the sandhi along with the identification of the sandhi between the given words, which the AD's sandhi rule is derived from. User-supplied words, samhitā/sandhi words, sandhi identity, siddhi codes are obtained in this analysis form. Based on the analysis provided by this system, all the sandhi forms have been made. Presents all the information of accomplishment like *sūtras*, *vārtikas*, rules, definitions etc. in text form with hyperlinked meaning and explanation in the form of the automatic table of all those forms. This system is a very helpful resource for people who are curious about the sandhi and the form of the sandhi. By using this system the seeker can not only learn the sandhi himself. Rather, it can also be used as teaching material in the classroom for the teaching of sandhi.

This system achieves the then sandhi and *rūpasiddhi*. As a result, this web-based style affects teaching as well as attracts students' attention to the reading process. The use of the book is of limited consequence. Whereas the use of the system is of unlimited consequence. This system is available online 24\*7. Therefore, it can be used without compulsion at any time in reading and learning. Therefore, this system will prove to be very effective in e-learning.

## 10. Future Directions of the Research

This online sandhi system has been designed according to the *Vayakaranasiddhāntakaumudī*. This system gives sandhi and its Derivational Process between any two words or two varṇa. This system will play a very effective role in Digital classroom teaching, boosting teaching skills and the learning process. In the context of information technology, this research will encourage innovation in future Sanskrit research works. This research will prove to be helpful in future research work on other topics of Sanskrit grammar process like *subanta*, *tiṅanta*, *ṇijanta*, *yaṅanta*, *sanādyanta*, *samāsa*, *taddhita* etc. With the help of this system, the development of *Sasūtrarūpasiddhi* Sandhi Splitter system can be done which will prove to be very important in the world of Sanskrit literature. Presently this system has been made in the Hindi version only. After that, it can also be developed for another language versions such as Sanskrit, English, Bangla, Tamil, Telugu etc. And speech technology can also be used for input-output in this.

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