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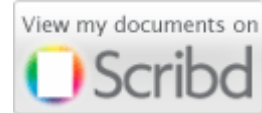
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EDITORIAL

Now in its fifth edition, IJCSI has established itself as a venue for excellence in the area of scientific publications and dissemination of knowledge. With its open access policy, IJCSI will continue to serve the scientific community in its utmost capacity. The quality of a journal is mostly dependent on the quality of papers it received and published. IJCSI has shown its level of quality through articles that it has published so far.

Readers are encouraged to recommend to their institutions to subscribe to IJCSI proceedings.

We would like to thank enormously all reviewers of IJCSI who have been servicing IJCSI so far.

IJCSI will always maintain its activity of sending all corresponding authors a free print copy of the journal.

We are pleased to present IJCSI Volume Fifth (IJCSI Vol. 5). This issue attracted a total of 28 papers out of which 7 papers have been accepted with minor revisions, 16 were sent back for major revisions and 5 were full reject. The paper acceptance rate for this volume is 25%.

As always, we sincerely hope you would find important ideas, concepts, techniques, or results in this issue that might be important for your research activities.

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Digital Image Watermarking for Arbitrarily Shaped Objects Based On SA-DWT

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Abstract

Many image watermarking schemes have been proposed in recent years, but they usually involve embedding a watermark to the entire image without considering only a particular object in the image, which the image owner may be interested in. This paper proposes a watermarking scheme that can embed a watermark to an arbitrarily shaped object in an image. Before embedding, the image owner specifies an object of arbitrary shape that is of a concern to him. Then the object is transformed into the wavelet domain using in place lifting shape adaptive DWT (SADWT) and a watermark is embedded by modifying the wavelet coefficients. In order to make the watermark robust and transparent, the watermark is embedded in the average of wavelet blocks using the visual model based on the human visual system. Wavelet coefficients n least significant bits (LSBs) are adjusted in concert with the average. Simulation results show that the proposed watermarking scheme is perceptually invisible and robust against many attacks such as lossy compression (e.g. JPEG, JPEG2000), scaling, adding noise, filtering, etc.

Keywords: Watermarking, Visual model, Robustness, Shape adaptive-discrete wavelet transform.

1. Introduction

With the rapid growth of Internet technologies and wide availability of multimedia computing facilities, the enforcement of multimedia copyright protection becomes an important issue. Digital watermarking, one of the popular approaches considered as a tool to achieve this goal, is a technique based on embedding a specific mark or signature into the digital products. Many watermark algorithms have been proposed to address this issue of copyright protection. Cox et al. [1] propose a DCT based spread spectrum watermarking technique. A pseudo-random sequence is embedded into the significant DCT coefficients and is retrieved by calculating the similarity

function of the original watermark and extracted watermark. Su et al. [2] proposes a wavelet-based watermark algorithm. Based on the principle of multithreshold wavelet codec (MTWC), the method searches the significant wavelet coefficients to embed the watermark in order to increase the robustness. The embedding strength in each subband is determined by the threshold of the subband. Polilchuk and Zeng [3] propose two kinds of adaptive watermarking methods. One is based on discrete cosine transform (IA-DCT), the other is based on discrete wavelet transform (IA-W). The watermark is embedded according to the JND threshold. Kaewkamnerd et al. [4] propose a wavelet based adaptive watermarking scheme. The human visual system (HVS) is employed to determine the weighting function $T(x,y)$ to control the watermark casting process.

The problem with the current watermarking algorithms is that most of them embed a watermark in the entire image without taking the content of the image into account. In some situations, the image owner may be more interested in an object of an image than the whole image, so it's desirable to embed a watermark in the object to protect it better. To address this problem, Guo and Georganas [5] propose a watermarking scheme that can embed a watermark to an arbitrarily shaped object in an image. Before embedding, the image owner specifies an object of arbitrary shape that is of a concern to him. Then the object is transformed into the spectrum domain using shape adaptive DCT and a watermark is embedded by modifying the spectrum coefficients in an additive way. But the watermark can be damaged by a wavelet-based image codec. Therefore, this method limits their applications in the context of JPEG2000 due to the fact that the wavelet transform is playing an important role in JPEG2000. Kong Yu and Liu [6] propose a novel blind object watermarking scheme for images using SA-DWT.

To make the watermark robust and perceptual invisible, the watermark is embedded in the weighting mean of the wavelet blocks using the quantisation visual model based on HVS. The visual model takes into account the brightness sensitivity and texture sensitivity. Watermark detection is accomplished without the original, unwatermarked object by using statistical detection technique. This technique is robust against many attacks such as lossy image/video compression (e.g. JPEG, JPEG2000), scaling, adding noise, filtering, D/A and A/D conversion, etc.

In this way, we propose in this paper a new blind watermarking scheme of images based on the in place lifting SA-DWT. The watermark signal is embedded in the wavelet coefficients n LSBs. Unlike most watermark schemes, watermark embedding is performed by modulating the average of the wavelet coefficients instead of the individual coefficients in the wavelet block. Visual model is employed to achieve the best tradeoff between transparent and robustness to signal processing. Watermark detection is accomplished without the original. Experimental results demonstrate that the proposed watermarking scheme is perceptually invisible and robust against unintentional and intentional attacks such as lossy image compression (e.g. JPEG, JPEG2000), scaling, adding noise, filtering.

The rest of the paper is organized as follows:

Section 2 briefly introduces the in place lifting shape adaptive DWT. In section 3, the proposed scheme is introduced and section 4 presents some experimental results. Finally, this paper concludes with section 5.

2. In-Place Lifting SA-DWT

Given an arbitrarily shaped object with shape mask information, with in place lifting SA-DWT[7], the number of transformed coefficients is equal to the number of pixels in the arbitrarily shaped segment image, and the spatial correlation across subbands is well preserved. Fig. 1 illustrates the result of one-level wavelet decomposition of an arbitrarily shaped object.

The in-place lifting DWT implementation has special implications for the SA-DWT[8], which can best be understood visually as shown in Fig.1. As the SA-DWT is performed, the spatial domain shape mask remains intact with no requirement to derive a shape mask for each subband. How the subbands are arranged in this pseudo-spatial domain arrangement is shown in Fig. 2(a). Each subband can in fact be extracted from the interleaved subband arrangement using the lazy wavelet transform (LWT) [9]. After the one-level SA-DWT is performed, the LL1 subband can be extracted using a coordinate mapping

from the interleaved subband coordinates (i,j) to the LL1 subband coordinates (i_{LL1},j_{LL1}) as follows:

$$(i_{LL1}, j_{LL1}) \leftarrow ([i/2], [j/2]) \quad (1)$$

Similarly, the mapping for the HL1 subband is

$$(i_{HL1}, j_{HL1}) \leftarrow ([i/2]+1, [j/2]);$$

for the LH1 subband $(i_{LH1}, j_{LH1}) \leftarrow ([i/2], [j/2]+1)$; and for the HH1 subband $(i_{HH1}, j_{HH1}) \leftarrow ([i/2]+1, [j/2]+1)$.

After the first level of the SA-DWT, the interleaved subband arrangement is made up of 2×2 basic blocks of coefficients. As shown in the left side of Fig. 2 (b), the top-left coefficient of each block is an LL1 subband coefficient, the top-right coefficient is an HL1 subband coefficient, and so on the second level SA-DWT is performed by first extracting the LL1 subband using the coordinate mapping (1) and then performing the one-level SA-DWT using the LL1 subband as the new input. The output is the four interleaved subbands, LL2, HL2, LH2, and HH2. This is then placed back into the original interleaved subband arrangement where the LL1 coefficients were extracted from. This creates a two-level interleaved subband arrangement. As shown in the middle of Fig.2(b), the two-level interleaved subband arrangement is made of a basic 4×4 coefficient block, with the top-left coefficient of each block being an LL2 coefficient. The coordinate mappings to extract the second and subsequent level subbands are simply derived by applying the one level coordinate mappings iteratively to the LL subband coordinate mapping from the previous level.

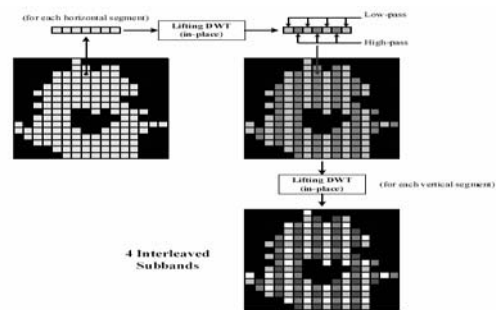


Fig. 1 One-level, two-dimensional SA-DWT using in-place lifting DWT implementation

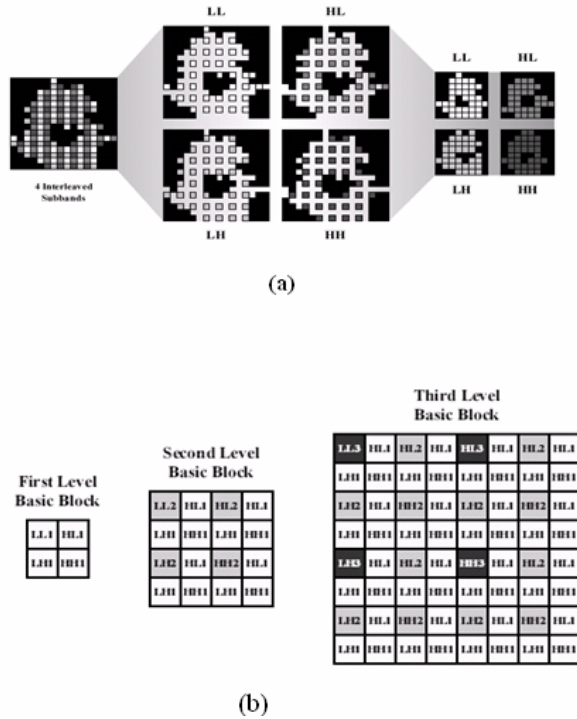


Fig. 2 (a) Interleaved subband abstraction (b) Basic group of coefficients for each level of in-place DWT.

3. Proposed Watermarking Scheme

A content-based watermarking system for content integrity protection is illustrated in Fig 3.

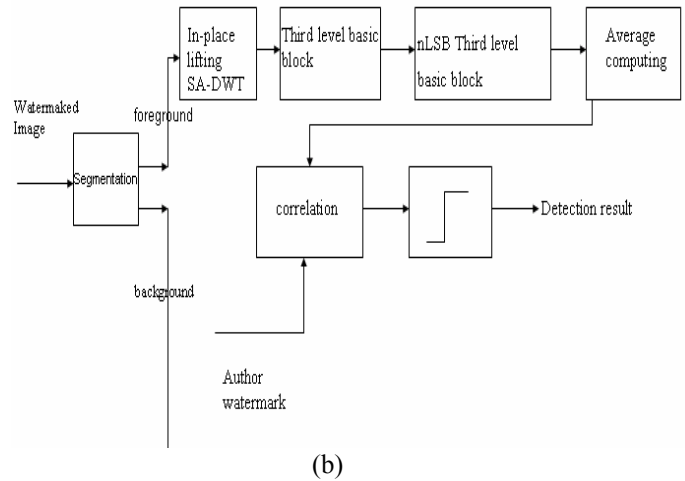
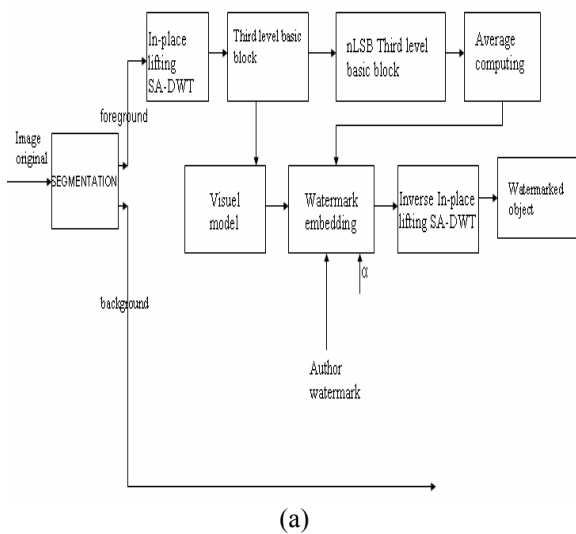


Fig. 3 Block diagrams for the proposed watermarking scheme. (a) Watermark embedding. (b) Watermark detection.

3.1 Watermark Embedding

Fig.3(a) shows the watermarking embedding procedure. First instead, the original image is segmented into foreground (object) and background and we apply the three levels in place lifting SA-DWT to foreground object. Then we take each third level basic block (see Fig 2(b)). $N \times N$ is the size of the matrix wavelet block and $I_i(k)$ is the i th wavelet coefficient in the k th wavelet block where $i \in [1, N \times N]$.

The rest of the watermarking embedding procedure is presented in the following. The n LSBs of $I_i(k)$ is defined as :

$$\hat{I}_i(k) = \text{mod}(I_i(k), 2^n) \tag{2}$$

The average of the wavelet block is defined as follows:

$$\text{Average}(k) = \frac{\sum_{i=1}^{N \times N} \hat{I}_i(k)}{N \times N} \tag{3}$$

In the proposed watermarking, we choose the blocks with an average value different from zero.

If a few of $I_i(k)$ are changed by Ω due to some distortions, the average of the wavelet block will only have a small change[6]. Assuming that $I'_i(k)$ is the i th wavelet coefficient in the k th wavelet block after the watermark embedding, $\hat{I}'_i(k)$ is the n LSBs of $I'_i(k)$ and $\text{Average}'(k)$ is the average of $\hat{I}'_i(k)$ in the k th wavelet block accordingly. The watermark W , consisting of a binary pseudo random sequence, $W(k) \in \{-1, 1\}$, is

embedded by adjusting the average of wavelet blocks in this way :

$$Average'(k) \in \begin{cases} [0, 2^{n-1}), \text{if } W(k) = -1 \\ [2^{n-1}, 2^n), \text{if } W(k) = 1 \end{cases} \quad (4)$$

To adapt the watermark sequence to the local properties of the wavelet block, we use the model based on HVS in the watermark system. The visual model function $Vm(k)$ is defined as:

$$Vm(k) = \text{brightness}(k) \times \text{texture}(k)^\beta \quad (5)$$

Where

$$\text{texture}(k) = \frac{\sum_{i=1}^{N \times N} [\text{brightness}(k) - I_i(k)]^2}{N \times N}$$

$$\text{brightness}(k) = \frac{\sum_{i=1}^{N \times N} I_i(k)}{N \times N}$$

β is a parameter used to control the degree of texture sensitivity. This visual model function indicates that the human eye is less sensitive to noise in the highly bright and the highly textured areas of the image. Hence, the wavelet blocks are divided into two parts depending on the value of $Vm(k)$: high activity wavelet block and low activity wavelet block. For simplicity, the threshold Tc is set to the average of $Vm(k)$. The following function can be applied to distinguish high or low activity wavelet block:

$$T(k) = \text{sign}(Vm(k) - Tc) \quad (6)$$

Considering the tradeoff between robustness and transparency, the proposed watermark embedding algorithm can be formulated as follows:

$$\hat{I}_i(k) = I_i(k) + \alpha W(k) F_i(k) [2^{n-2-S(k)} + T(k) \times 2^{n-3}] \quad (7)$$

where α is a scaling factor used to control the strength of the inserted watermark. The flag function is defined as follows:

$$F_i(k) = \text{sign}((2^{n-1} - \hat{I}_i(k)) \times W(k)) \quad (8)$$

Where

$$\text{sign}(x) = \begin{cases} 1 & \text{if } x \geq 0 \\ -1 & \text{if } x < 0 \end{cases}$$

The strength function is defined as follows:

$$S(k) = \text{sign}(X(k)) \quad (9)$$

Where

$$X(k) = (2^{n-1} - \text{Average}(k)) \times W(k)$$

Details concerning the flag function and the strength function are described in table 1.

Table 1. The detailed results of $F_i(k)$ and $S(k)$

W(k)	$2^{n-1} - \hat{I}_i(k)$	$2^{n-1} - \text{Average}(k)$	F(k)	S(k)
-1	>0	>0	-1	-1
-1	≤0	≤0	-1	-1
1	>0	>0	1	1
1	≤0	≤0	1	1

In light of the above, the n LSBs of wavelet coefficients have been adjusted by using equation (6). Naturally, their average has been updated depending on the requirement of $W(k)$ as show in equation (3). In other word, the watermark has been embedded.

3.2 Watermark Extraction and Detection

The watermark sequence can be extracted without the original object. From the process of the watermark embedding, we can obtain the watermarked objects by applying the function of equation (3). Thus, for a given watermarked object, the watermark can be extracted as

$$W'(k) = \begin{cases} -1, & \text{if } \text{Average}(k) \in [0, 2^{n-1}) \\ 1, & \text{if } \text{Average}(k) \in [2^{n-1}, 2^n) \end{cases} \quad (10)$$

In order to detect the watermark W' extracted from the watermarked object, First instead we evaluate the detector response (or similarity of W' and W) as :

$$\rho(W', W) = \frac{\sum_{k=1}^L W'(k) \times W(k)}{\sum_{k=1}^L \|W'(k)\|^2} = \frac{\sum_{k=1}^L W'(k) \times W(k)}{L} \quad (11)$$

Where, L is the length of the watermark signal. The Threshold $T\rho$ is set so as to minimize the sum p of the probability of error detection and the probability of false alarm. if $\rho \geq T\rho$, we considered the watermark is present, otherwise absent.

4. Experiments Results

Simulations are carried out for several standard monochrome images as shown in Fig. 4 but only report result in detail for 704 x 480 akiyo. In our experiments, the parameters considered are: the threshold $T\rho = 0.1$, $\beta = 0.318$, $n = 5$, $N=8$ wavelet-level = 3, wavelettype = 'haar', $L = 1700$ and scaling factor $\alpha = 0.3$.

In order to test the performance of the proposed watermarking scheme, 200 watermarks were randomly generated.

The PSNR result between the original object and the watermarked object is 39.26 dB. As shown in Fig. 5, the watermark is perceptual invisible and the object with watermark appears visually identical to the object without watermark. In Fig. 6 the absolute difference between the original object and the watermarked one, it is evident that there is no watermark embedded in the region outside the object. Fig. 7 shows the response of the watermark detector to 200 randomly generated watermarks of which only one matches the watermark present. The response to the correct watermark (i.e. number 100) is much higher than the responses to incorrect watermarks.

To evaluate the robustness of our scheme against unintentional and intentional attacks, we test the watermarked object with JPEG, JPEG2000, scaling, adding noise, filtering, and multiple watermarking attack. Added experiment results for other images are listed in Table 2.



(a)



(b)



(c)

Fig. 4 (a)Original image (object) akiyo, (b)Original image (object) News, (c)Original image (object) Scene.



Fig. 5 Watermarked object akiyo (PSNR=39.26 dB)

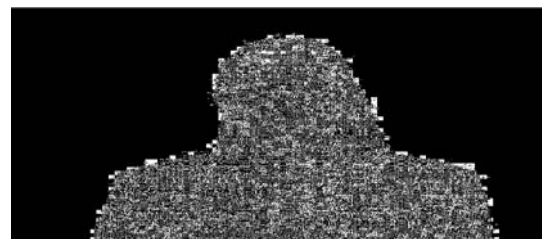


Fig. 6 Absolute difference between the original object and the watermarked

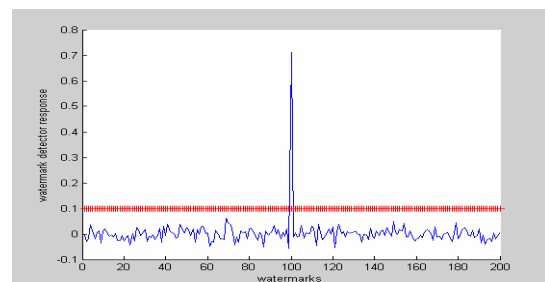


Fig. 7 Detector response of the watermarked object akiyo for 200 randomly generated watermark

4.1 JPEG Compression Distortion

JPEG is a widely used compression format and the watermark should be resistant to it. As shown in Fig.8, with the decreasing of the quality of the JPEG compressed object, the response of the watermark detector also decreases. We have found that the proposed watermark can survive even with quality factor of 40% (see Fig.9), although the object is visibly non distorted (see Fig.10)

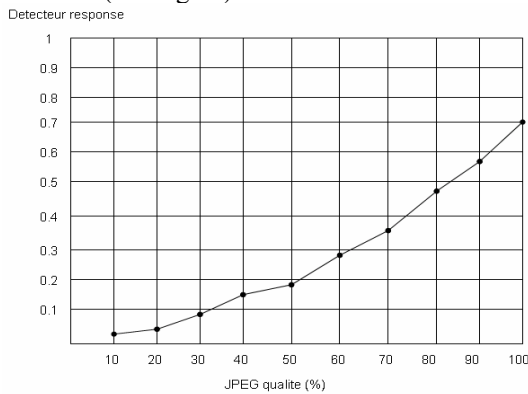


Fig. 8 Watermark detector response on the decreasing of the quality of the JPEG compressed object 'akiyo'

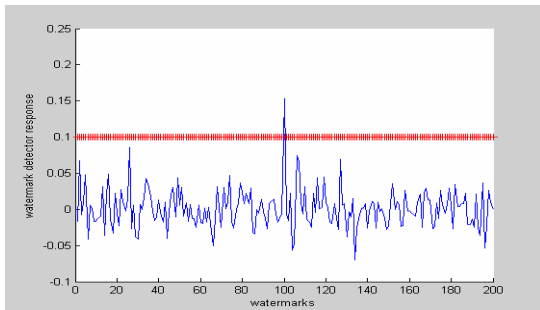


Fig. 9 Detector response to a JPEG compression copy of the watermarked object 'Akiyo' with 40% quality.



Fig. 10 JPEG compressed copy of the watermarked object 'Akiyo' with 40% quality.

4.2 JPEG2000 Compression Distortion

JPEG2000 is the new generation compression standard, which is based on wavelet transform. In our experiments, we test the watermarked object with JPEG2000 compression. The detector response of the watermarked object Akiyo after the JPEG2000 compression with 75% quality is 0.3729. Fig. 11 shows the object after the JPEG2000 compression with 65% quality, which results in very significant distortion. The response of the watermark detector in this case is 0.2053, which is still above the threshold T_c (see Fig.12).



Fig. 11 JPEG2000 compression copy of the watermarked object 'Akiyo' with 65% quality.

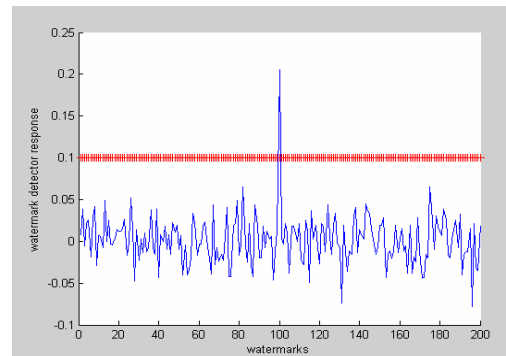


Fig. 12 Detector response to a JPEG2000 compression copy of the watermarked object 'Akiyo' with 65% quality.

4.3 Adding Noise

Noise is one of common distortions in image processing and transmission. In the experiment, we add 30% uniform noise, 0.1% Gaussian noise and 20% Laplacien noise into the watermarked object as shown in Figs. 13, 14 and 15. The watermark can still be retrieved successfully, and the responses of the watermark detector are 0.5463 , 0.1176 and 0.3080 .



Fig. 13 Watermarked object 'Akiyo' after 30% uniform noise adding.



Fig. 14 Watermarked object 'Akiyo' after 0.1% Gaussian noise adding.



Fig. 15 Watermarked object 'Akiyo' after 20% Laplacian noise adding.

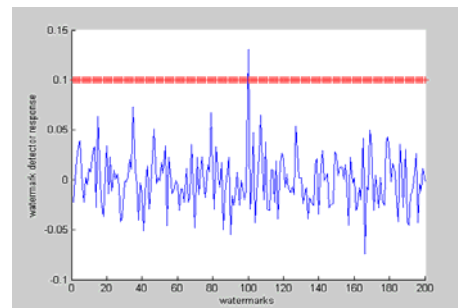
4.4 Filtering

Filtering is very common in image processing. The watermarked object was filtered with 3×3 blur filter and 5×5 median filter (see Fig.16 and 17). The responses of the watermark detector are 0.2248 and 0.2428. These responses are well above the threshold T_c , even if the objects appeared degraded.

Fig. 16 Watermarked object 'Akiyo' after 3×3 blur filteringFig. 17 Watermarked object 'Akiyo' after 5×5 median filtering

4.5 Rescaling

Scaling is also very easy to perform during the editing of digital images. So the watermark technique must be robust to the scaling attack. We test our scheme in the case of scaling the watermarked object by 0.5×0.5 . The experiment results show the watermark can still be retrieved as shown in Fig.18 et 19 with the detector response 0.1308.

Fig. 18 Watermarked object 'Akiyo' after Rescaling 0.5×0.5 rescaling (50%)Fig. 19 Detector response of 0.5×0.5 rescaling

4.6 Multiple Watermarking Attack

The original object is watermarked, then the watermarked object is again watermarked, and so on until the object with different watermarks is obtained (see Fig. 20). The detector performs well in retrieving all the two watermarks embedded in the object, as shown in Fig. 21.



Fig. 20 The object 'Akiyo' with two different watermarks.

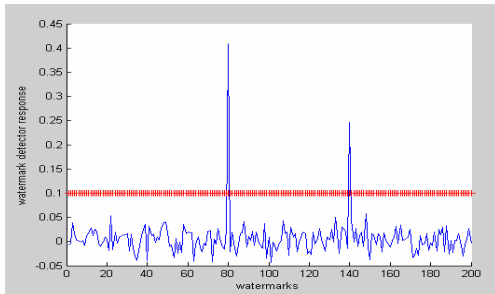


Fig. 21 Detector response of the multiple watermarked object 'Akiyo'

Table 2: Watermark detector responses after attacks

Detector responses	akiyo	News	Sean
Sans attack	0.7101	0.7212	0.7131
JPEG quality 65%	0.2435	0.3535	0.3944
JPEG quality 70%	0.3102	0.4077	0.4606
JPEG quality 85%	0.4676	0.5253	0.5962
JPEG2000 quality 65%	0.3491	0.3652	0.5245
JPEG2000 quality 75%	0.4231	0.4179	0.6481
JPEG2000 quality 85%	0.5296	0.5499	0.6922
Uniform noise 10%	0.6673	0.6798	0.7022
Uniform noise 20%	0.6024	0.6266	0.6470
Uniform noise 30%	0.5338	0.5693	0.6040
Uniform noise 100%	0.1556	0.2510	0.2984
Laplacien noise 20%	0.2298	0.5478	0.3867
Gaussian noise 10%	0.1357	0.1018	0.1307
Blur filtering 3 * 3	0.1983	0.1714	0.2752
Median filtering 5 * 5	0.2224	0.3790	0.4175
Gaussian filtering	0.6404	0.6726	0.6801
Scaling 75%	0.2382	0.2072	0.2918
Scaling 50%	0.1084	0.1161	0.2190

5. Conclusions

This paper proposes a watermarking scheme that can embed a watermark to an arbitrarily shaped object in an image. Before embedding, the image owner specifies an object of arbitrary shape that is of a concern to him. Then the object is transformed into the wavelet domain using the in place shape adaptive wavelet transform and a watermark is embedded by modifying the wavelet coefficients. Experimental results show that this scheme is robust to common signal processing procedures such as compression, median filtering and additive noise.

Efficiency of the method is revealed on the basis of the following results:

(1) The average has a smaller change than that of individual coefficient. Thus, unlike most watermarking schemes, the watermark is not embedded by just an individual wavelet coefficient but by modulating the average of the wavelet blocks.

(2) Visual model allowed to achieve the best tradeoff between transparency and robustness.

(3) Watermark detection is accomplished without the original.

(4) Many parameters can be used as private key to that they are unknown to public.

(5) This algorithm can be used for MPEG4 video watermarking

The proposed scheme was compared to the Xiangwei Kong's scheme [6]. The insufficiencies of our proposed approach are that robustness is relatively inferior to the Gaussian noise that needs exploration in our work in future.

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ANN-based Innovative Segmentation Method for Handwritten text in Assamese

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Abstract

Artificial Neural Network (ANN) s has widely been used for recognition of optically scanned character, which partially emulates human thinking in the domain of the Artificial Intelligence. But prior to recognition, it is necessary to segment the character from the text to sentences, words etc. Segmentation of words into individual letters has been one of the major problems in handwriting recognition. Despite several successful works all over the world, development of such tools in specific languages is still an ongoing process especially in the Indian context. This work explores the application of ANN as an aid to segmentation of handwritten characters in Assamese- an important language in the North Eastern part of India. The work explores the performance difference obtained in applying an ANN-based dynamic segmentation algorithm compared to projection- based static segmentation. The algorithm involves, first training of an ANN with individual handwritten characters recorded from different individuals. Handwritten sentences are separated out from text using a static segmentation method. From the segmented line, individual characters are separated out by first over segmenting the entire line. Each of the segments thus obtained, next, is fed to the trained ANN. The point of segmentation at which the ANN recognizes a segment or a combination of several segments to be similar to a handwritten character, a segmentation boundary for the character is assumed to exist and segmentation performed. The segmented character is next compared to the best available match and the segmentation boundary confirmed.

Keywords: Segmentation, Classification, Handwritten, Cursive, Recognition, Dissection.

1. Introduction

Artificial Neural Network (ANN)s have been preferred tools for pattern recognition including optical characters which broadly constitutes an important segment of Computer Vision and Machine Learning. This is because ANNs have the capacity to learn, adapt to changing environments and demonstrate a computational paradigm that resembles the parallelism generated by the human brain. That way ANNs are smart tools and can be applied

for a host of pattern recognition and prediction problems [1]. ANNs have two phases of working- first training during which it learns the patterns and testing which ascertains the extent of learning.

Optical Character Recognition (OCR) is a common and popular example of application of ANNs for pattern recognition. OCR refers to a process of generating a character input by optical means, like scanning, for recognition in subsequent stages by a smart tool like ANN by which a printed or handwritten text can be converted to a form which a computer can understand and manipulate. A generic character recognition system may be shown in figure 1. Its different stages are as below:

- **Input:** Samples are read to the system through a scanner.
- **Preprocessing:** Preprocessing converts the image into a form suitable for subsequent processing and feature extraction.
- **Segmentation:** The most basic step in OCR is to segment the input image into individual *glyphs*. This step separates out sentences from text and subsequently words and letters from sentences.
- **Feature extraction:** Extraction of features of a character forms a vital part of the recognition process. Feature extraction captures the vital details of a character.
- **Classification:** During classification, a character is placed in the appropriate class to which it belongs. Character classification is roughly categorized as *Sub-symbolic classifiers* and *Symbolic classifiers*. The ANN approach is classified to be a sub symbolic classifier [2].

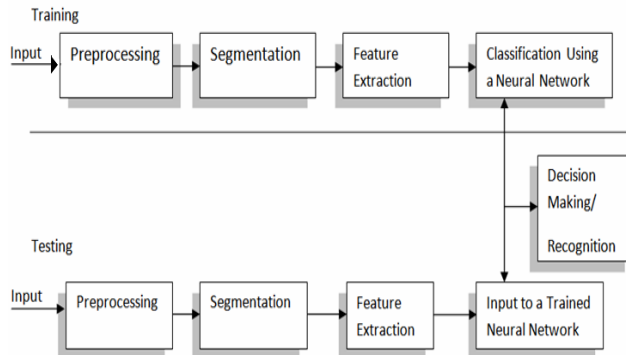


Fig-1 Block diagram Character Recognition System

As mentioned in [3], [4], segmentation plays an important role in the overall process of recognition of printed and handwritten characters. This is more so with **cursive** writing. Success and failure of an OCR system depends on the segmentation process. But this description is related to a work that attempts to use ANNs for the segmentation stage of an ANN based OCR system exclusively for Assamese which is an important language in NE region of India. The reasons behind the use of ANNs for segmentation are as below:

1. Static segmentation method suffers from a serious drawback that it cannot fix segmentation boundaries for cases where inputs have size and inclination variations.
2. Static Segmentation methods also fail to fix segmentation boundaries for cases where there are writer induced variations in inputs. Figure 2 shows the failure of static segmentation methods in dealing with writer induced variations.

The solution for such cases can be given by ANNs these have the ability to learn shapes and that way discriminate segmentation boundaries.

ANNs have been used for several character recognition systems. Some of the segmentation methods relevant in practice is described in [3]. For cursive writing Cheng, Liu et. al [5] provides a description of available segmentation methods. Use of ANNs for segmentation has been reported by Blumenstein [6]. Other similar works are [7], [8], [9], [10], [11], [12], [13] to name a few. Very few known attempts have been reported regarding use of ANNs for segmentation in the Indian OCR scenario.

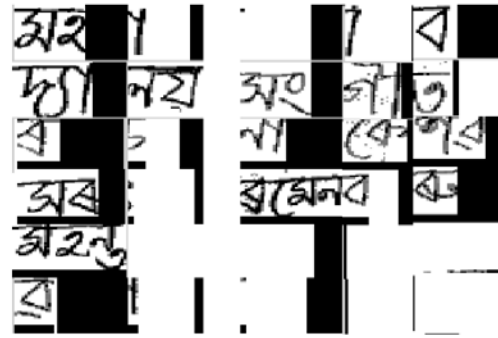


Figure 2: Segmented output of the hand written characters

Section 2 provides an insight into certain features of Assamese scripts. Details of experimental work have been included in section 3. Use of ANNs for segmentation and related description has been covered in section 4. Section 5 concludes the description.

2 Basic features of Assamese Handwritten Characters:

1. Assamese characters can trace their roots to Brahmi script and has evolved over the years through modifications.
2. Assamese script formed by 11 vowels, 40 consonants, over 10 modifiers and over 300 compound characters. The use of upper and lower case letters like in English is not there in Assamese as in other languages including Bengali.
3. There is a use of head line (called *matra* in Assamese) in certain characters including consonant and vowels. It helps in segmentation of the characters easily but as many of the segmented characters with their head lines missing appears similar making classification difficult.
4. A typical Assamese word maybe classified into three Jones as in Figure 3

- **Upper Zone** Area above the head line. It is characterized by the presence of extensions of the modifiers.
- **Middle Zone** Area where the main body of the character lies.
- **Lower Zone** Area where some of the modifiers exists.

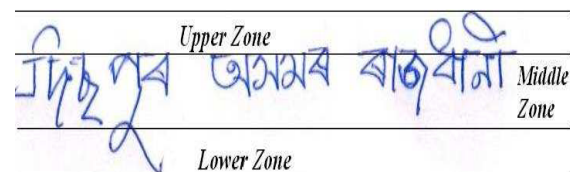


Figure 3: Assamese words with three different zones

3. Detail of the Experimental Work

The work conceptualized an ANN based OCR system where segmentation is done by a multi-layered perceptron (MLP)- a class of feed forward neural network. The MLP is trained to do so. The algorithm involves, first training of an ANN with individual handwritten characters extracted from different individuals. Handwritten sentences are separated out from text using a static segmentation method. From the segmented line, individual characters are separated out by first over segmenting the entire line. Prior to all these steps some preprocessing steps are required for the scanned image. These are:

1. Noise removal: It involves noise removal using certain filtering operations.

2. Enhancement: Here the filtered images are enhanced using certain high boost filter makes and histogram equalization technique.

3. Sharpening: For degraded or blurred images after noise cleaning operations sharpening may be done.

4. Binarisation: After enhancement and sharpening the gray level image is converted into binary form so as to ease the computational load of the subsequent stages

5. Normalization: The images just before the segmentation stage are converted to certain standard sizes. If the input has inclination and skew, respective corrections are done. After preprocessing the next step is segmentation of the input. During this stage first lines are separated out from the text first into lines and then the words are next segmented into the individual characters. The approach adopted here is a projection -based one. A brief outline of the static segmentation method is as below:

1. Row -wise dissection:

- Calculate row-wise pixel sums of the inputs
- Obtain the row -wise projection of the inverted inputs
- Find the minimum of the projections
- A pair of closely lying minimum points defines one segmentation boundary.
- Dissection boundaries give sub-images of inputs. Hold them in an array.

2. Column-wise dissection:

For each entry into the array as above

- Calculate the sum of pixels column-wise.
- Obtain the column-wise projection of the inverted sub-images.
- Find the minimum points from these projections
- A pair of consecutive minimum points defines one segmentation boundary.
- Store every character dissected out of the sub-image into an array. The array must also include space in between words.
- The array holds the segmented outputs of the segmented sub-images as obtained in step 1.

The results obtained are shown in Figures 2, 7 and 13. In certain cases character spacing is non-uniform, after the head-lines are removed. Base line character spacing then becomes comparable to word spacing. This affects word spacing. In such a situation morphological dilation maybe used as described in [14]. In case, modifiers are not separated from characters, especially in the case where modifiers are lying below the middle zone i.e. in the lower zone, the statistics of the horizontal projection is so obtained that a threshold is fixed that is 1.5 times the average line height. The non-zero valleys below the threshold indicate the separation boundary between the character and the modifier [14].

This method has certain drawbacks which are described in subsequent stages.

3.1 Similarity Measure

A similarity measure for the machine printed characters may be defined as:

$$S = \left(1 - \frac{\sum I_{seg}(i, j)}{\sum I_{ref}(i, j)} \right) * 100 \quad (1)$$

Where $I_{seg}(i, j)$ is the segmented image and $I_{ref}(i, j)$ is the reference image. For touching characters the segmentation method suffers and the similarity measures show lesser values. The segmentation method is not suitable for touching characters (Figure 2) and is useful more for printed characters which are a bit isolated (Figure 7). The method is useful in separating modifiers with italic characters as well (Figure 13). This is shown by the final segmented result of italic characters. The segmentation method is however capable of segmenting modifiers from the consonants despite their presence below and above the middle zone. Modifiers are decremented out to isolate the characters before feature extraction. The headline, similarly, can be segmented out which makes separation of the characters from individual words simpler. But this process also has the possibility of completely losing certain vital information regarding the characters.

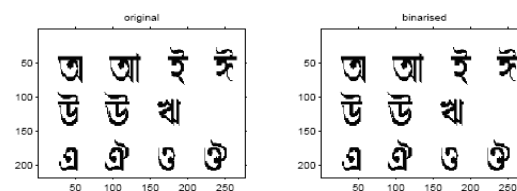


Figure 4: Pre-processed input of vowels

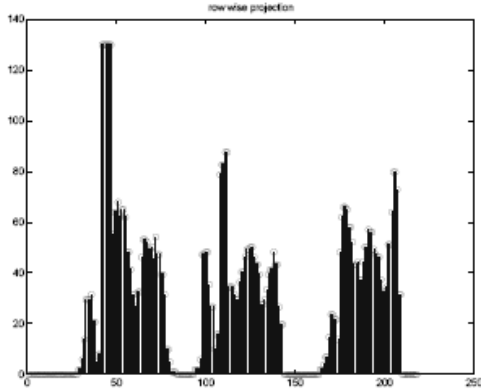


Figure 5: Horizontal Projection of the vowels

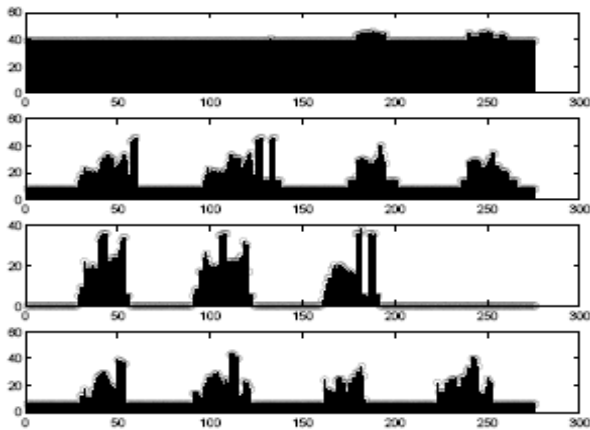


Figure 6: Vertical segmentation of vowels

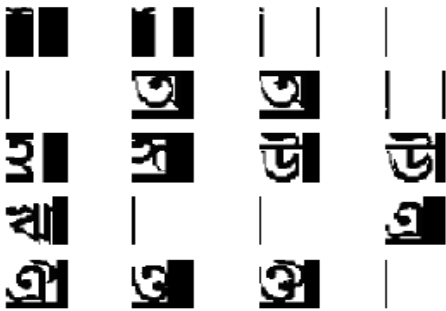


Figure 7: Segmented output of the vowels

The values of similarity measure for different segmented characters are shown as in Table-1. A higher value of the similarity measure directly improves the classification and recognition rates subsequently. An improved method for segmentation may yield higher values of the similarity measure than has been found in the present work. The result obtained from static segmentation was found not to be healthy for handwritten characters (Figure 2). The basis of the ANN based segmentation method has been developed keeping into account the failure shown by the static method (Figure- 2). The steps of ANN based segmentation may be described as below.

1. ANN trained with all available Assamese characters.

2. Sentences are separated out from text using static method.

- On sentences thus obtained an over segmentation is done. The over segmentation is done at an interval of 2:5% length to that of that total length of the sentence separated (fig 8).
- Each of the segment obtained from the sentence due to the over segmentation (fig 8) are fed to the trained ANN.
- If due to the feeding of first segment the ANN fails to recognize, the next segment is fed together. This process is repeated till the ANN recognizes a complete character (Figure 9).
- The recognition performances of the trained ANN then are determined. A successful recognition by the ANN provides a demarcation and generates a segmentation boundary.
- This process is repeated till the segmentation boundaries for the entire sentence and then the text is completed.

Table 1: Similarity Measure values obtained using static segmentation

Pronunciation	S in %
A	86
AA	82
E	92
EE	92
U	92
UU	92
RI	82
AE	90
AOI	90

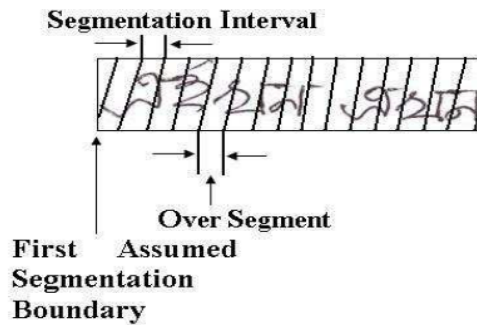


Figure 8: Segmentation boundary Measure

The entire work maybe depicted by the figure 14.

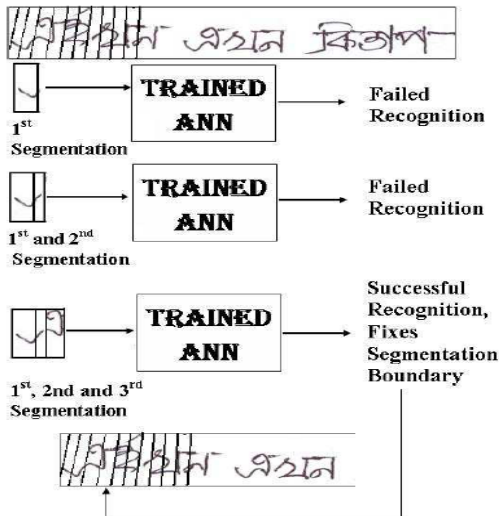


Figure 9: Segmentation Process Using trained ANN

4. ANN Based Segmentation

First the ANN is trained with individual Assamese characters. This ANN will handle the recognition part of the segmentation process. To use an ANN for segmentation, it must be first trained. The training of the ANN takes into account the configuration of the ANN.

4.1 Configuration of MLP's

Several configurations of the MLP were utilized for training. These had one and two hidden layer configurations over and above the input and output layers. The one hidden layered configuration emerged as a trade-off between computational complexity and performance. The three layered MLP i.e, the one with one hidden layers had the following configuration:

Length of input layer = Normalized size of the input character,

Length of first hidden layer = 1.5 times of the feature vector,

Length of output layer=number of classes;

The two, three and four hidden layer MLP similarly had the varying hidden layer length configuration. The choice of the length of the hidden layers has not followed any definite logic but has been randomly selected.

Several methods of (Error) Back Propagation have been used for training the ANN. These are:

- Gradient Descent (GDBP).
- Gradient Descent with Momentum (GDMBP)
- Gradient Descent with Adaptive Learning rate Back propagation (GDALBP)
- Gradient Descent with Momentum and Adaptive Learning Rate BP(GDMALRBP)

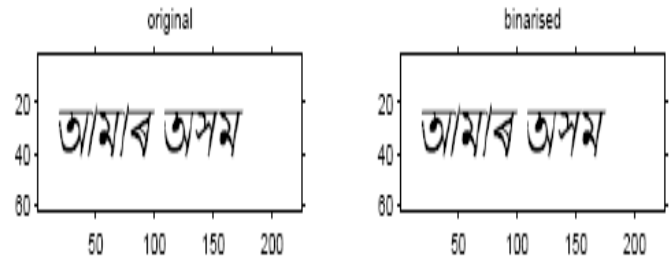


Figure 10: Pre-processed input of italic characters

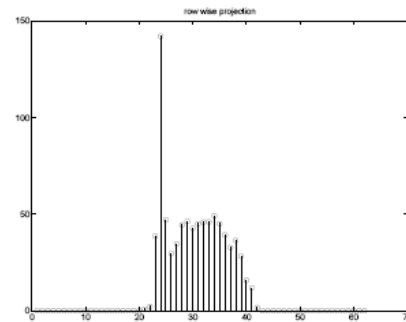


Figure 11: Horizontal Projection of the italic characters

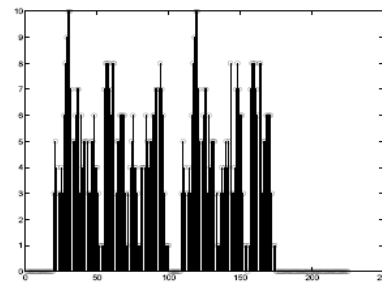


Figure 12: Column-wise segmentation of the italic characters



Figure 13: Segmented output of the italic characters

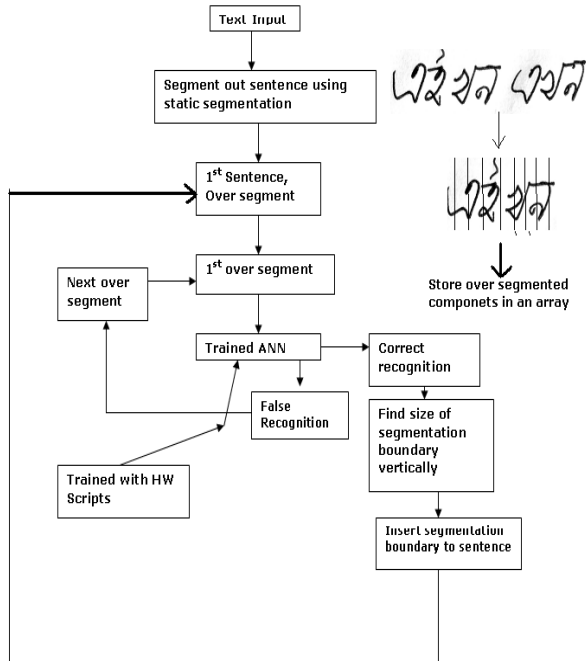


Figure 14: Detail Steps of the Present Work

The training input to the ANNs used for segmentation is a set of handwritten scripts a part of which is shown in Figure 15. The complete training set includes variations of twenty five different persons. For a three layered MLP the mean square error (MSE) attained after 1000 to 4000 training sessions is depicted in Table 2. Table 2 shows that the 3-layered MLP trained with GDMALRBP attains the best MSE convergence. Table 3 shows the classification performance of a three layered MLP trained with the four mentioned training methods. The GDMALRBP based training to the ANN generates the best classification performance. The ANN trained by following these considerations is taken for performing the segmentation of input handwritten scripts. The number of training sessions has been restricted between 1000 to 4000 training sessions. This is because with training epochs below 1000 the MLPs don't develop the ability to make discrimination between classes with success rates above 50%. Again with training sessions over 4000, there is always a chance of the ANNs losing the ability to generalize classes.



Figure 15: A section of characters forming training set of ANNs used for segmentation

Table 2: MSE attained during training by a three layered MLP with a learning rate of 0:4

Sessions	MSE attained with four different training methods			
	GDBP	GDMBP	GDALBP	GDMALRBP
1000	10.1×10^{-3}	9.1×10^{-3}	7.6×10^{-3}	6.23×10^{-3}
2000	1.02×10^{-3}	0.81×10^{-3}	0.71×10^{-3}	0.52×10^{-3}
3000	0.2×10^{-3}	0.08×10^{-3}	0.06×10^{-3}	0.04×10^{-3}
4000	0.05×10^{-3}	0.02×10^{-3}	0.01×10^{-3}	0.008×10^{-3}

The testing set includes handwritten scripts of twenty different persons writing in five different days. That way the testing set consists of over hundred samples. Moreover, noise has been added to check the versatility of the system and its ability to tackle variations in input conditions. A set of test samples generated by sentence-wise over-segmentation of the recorded samples using the static method and used to verify the dynamic segmentation ability of the selected MLP is shown in Figure 16. The average results of the segmentation thus carried out is expressed by the similarity measure referred to earlier in section 3.1. A comparison of the similarity measures obtained by the static and ANN based segmentation methods are shown in Table 4. The advantage of the ANN-based method is obvious.

Table 3: Classification performance in % by a three layered MLP trained with GDMALRBP with a learning rate of 0:4

Sessions	Classification rate in % four different training methods			
	GDBP	GDMBP	GDALBP	GDMALRBP
1000	87.1	90.3	91.3	92.2
2000	86.9	91.2	92.2	93.7
3000	89.1	92.3	93.6	95.4
4000	89.9	93.4	94.6	95.5

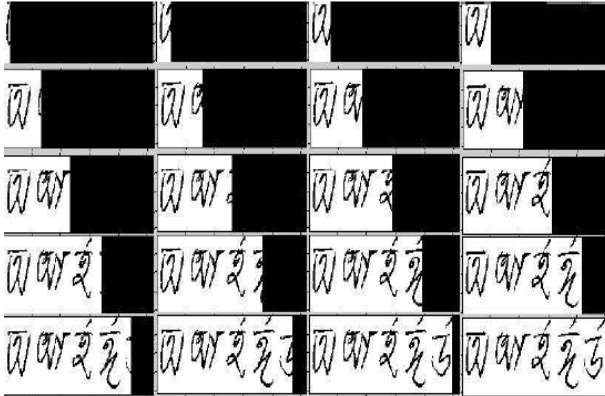


Figure 16: Testing set of ANNs used as combinations of over-segments

Table 4: Comparison of Similarity Measure (S) in % of five characters generated by static segmentation and by the selected ANN after 1000 to 4000 training sessions

Cases	Pronunciations	S with Static Segmentation	S in % between 1000 to 4000 training sessions			
			1000	2000	3000	4000
1	A	86	88.1	94.0	95.3	96.3
2	AA	82.0	84.4	90.1	92.2	93.2
3	E	92.0	92.3	92.9	94.0	95.0
4	EE	92.0	93.2	94.8	95.0	96.1
5	U	92.0	93.1	95.6	95.9	97.0

5. Discussion and Conclusion

The work offers an insight into development of a segmentation system for Assamese scripts using ANN. The work concentrates on improving the performance of the segmentation stage handling handwritten inputs with an aim to aid a character recognition system. The system tackles well non touching handwritten characters and even separates out partially touching characters without inclination but fails to tackle writing styles where characters are inclined and touching each other. Further development of the system can be a stage where touching handwritten characters can be handled by the system. The benefit of such a system is that it improves performance of segmentation which is so important in an OCR system. The ANN trained with different character shapes can be used as a decision making tool while selecting segmentation boundaries. As the segmentation boundary is fixed dynamically, the system can deal effectively with segmentation problems that suffer due to written induced variations in size and shape of characters without inclinations.

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Technology Integration around the Geographic Information: A State of the Art

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Abstract

One of the elements that have popularized and facilitated the use of geographical information on a variety of computational applications has been the use of Web maps; this has opened new research challenges on different subjects, from locating places and people, the study of social behavior or the analyzing of the hidden structures of the terms used in a natural language query used for locating a place. However, the use of geographic information under technological features is not new, instead it has been part of a development and technological integration process. This paper presents a state of the art review about the application of geographic information under different approaches: its use on location based services, the collaborative user participation on it, its contextual-awareness, its use in the Semantic Web and the challenges of its use in natural language queries. Finally, a prototype that integrates most of these areas is presented.

Keywords: *Geographic Information System, Location Based Services, Mashups, Semantic Web.*

1. Introduction

As the integration between technology and society grows up, the task of accessing and retrieving information becomes a crucial point for decision-taking activity, caused by the ever growing user's needs. These needs are resumed in a more natural, faster and pertinent information retrieval; these desirable features are considered because while searching for information, the user experience frequently becomes frustrating due to the impossibility of making a precise petition on the required form, also by the immense quantity of retrieved results or by the imprecision of them, in which there are irrelevant results meanwhile the really relevant responses are not found.

There are different fields in which the differentiation of the diversity of users takes a higher importance. That is the case for the searching of places and geo-located services, through a digital map for example. Under this focus, the use of located based services (LBS) let the user access to information for locating geographic places and points of interest (POIs), making this desirable to find and locate the more adequate ones to a user's particular need.

In recent years, it has become common the use of digital maps in hands of Google Maps, Yahoo Maps, Live Maps, among many others. The relevance of the geographic information has risen a great interest on users and development communities, which is manifested in the huge amount of APIs and mashups applications that have been appearing; there are different location based services, offered by mobile communication and services providers, e.g. there are services for route planning, city guides, hotel guides, etc; most of these applications are commercial or academic products that are generally focused on the locatable contextual dimension.

Other researches that consider the geo-located information to place searching includes the COMPASS 2008 project [1] which presents the use of ontologies towards a context-aware personalized information system, the tourist guide based on location from the Cyberguide project [2] which aimed to provide information to tourists based on their position, or the Lancaster City guide [3] in which according to the location and the user's preferences allows a visitor to get interesting information about the points of interest in the region.

It must be considered that the same user, under different circumstances is going to have different goals and purposes. On the field of geo-located services it is

important to consider the users' individual characteristics, because each person has different social, cultural and economical features, making his or her information needs implicitly different. This becomes necessary to have context-aware applications that consider the mentioned features in order to avoid the results that are not relevant to a particular user under specific spatial and temporal situations, at querying for locating places and services, such as hotels or restaurants.

However, since the amount of information has been continuously growing, the remaining data relevance problem and the information overload have become more serious. The use of semantics has been proposed to face up those problems [4], mainly through the use of ontologies. According with this, Perry et al. [5] presented an ontology based model that integrates the thematic, spatial and temporal dimensions, using a high level ontology that defines a general set of thematic classes and spatial entities, with associated relations that connect them. Other works for geographic ontology creation includes the development of a Web tool for this task [6], meanwhile [7], [8] and [9] are focused on the use of geographic domain ontologies for service description as a mean to counteract the ambiguity on user's queries.

The previous boards to another topic: the problems of vagueness inside natural language queries. In this respect, various attempts have been focused towards the identification and nature of natural language quantitative and qualitative prepositions used under geographic information domain with the purpose of a better understanding of determine what the user is trying to mean at querying [10].

The present paper gives a brief overview of the previous technologies and topics mentioned above considering its use related with the search of places and services through the use of geographic information. The uses that geographic information has today seem to cover a variety of research areas, each one with its own challenges. However, it can be seen that the developments among them could be integrated, giving to final users more reliable and personalized systems.

The content of the document is as follows: sections 2 to section 7 covers topics of Location Based Services (LBS), map mashups, collaborative geographic systems, context-awareness on LBS environments, the integration of geographic related information under the Semantic Web focus and the challenges from natural language querying for geographic information. Section 8 presents a prototype that integrates some of the previous topics, and finally conclusions are presented.

2. Geographic Information on Computer Maps and LBS

LBS (Location Based Services) are services that based on user's geographic location, can provide relevant information to his or her geographic position. The main purposes that a LBS system includes are the identification, search and verification of services that are nearby to a user's position, fulfilling tasks as identifying a user's location, locate other persons, objects or places, and provide guidance, information or help to find a particular place [11]. The main characteristic from LBS services is that they provide *just in time* information to the users, considering that the information presented must be from a particular domain of interest to the user and that this information be useful and can be used in the geographic area the user is at.

Steiniger [12] presents LBS systems as an infrastructure composed by: users, a communication network, a positioning component (such as a GPS), LBS service provider and data and content providers. The content provider turns to the service provider in order to obtain the geographic data and information needed to answer the user's query.

LBS design can be considered from two different approaches: *generic services*, in which a user explicitly denotes his or her location (i.e. giving street names or zip code) and *locatable services*, in which the location is automatically obtained in a transparent way to the user, using devices instead, as a GPS.

Also, LBS systems can be classified under different focuses, according to the activities they are going to be used for. For example, they are classified considering if they are going to be used for gaming, getting information or paying bills [13], meanwhile in [14] they are classified according the consumers.

There have been developed different formats in order to facilitate the managing of POIs information and users visited geo-routes between computer devices. These formats can be used for the representation of geographic location on Web maps, for example: LOC, GPX and KML, which are based on XML.

The earlier map applications on mobile devices worked the same visualization that the one used on desktops and on Internet; this presented some troubles due to the different situations that the mobile environment required, because mobile applications have had smaller screen displays in comparison to common desktop applications;

also, mobile applications are commonly used on open spaces, making its users' needs different.

These caused that the first difficulties that the LBS systems confronted, fallen on the type of interaction presented between the user and his or her mobile device, the device itself presented limitations caused by its portability; also on the limited visual representation of the earlier mobile devices, due by the low screen resolution, a limited bandwidth (situation which step by step has been counteracted with mobile technology advances such as the 3G network), and also due to the huge diversity of mobile devices, each one showing different functionalities, causing that it was necessary to develop particular device's applications. Actually, the diversity of installed platforms on mobile devices has started to unify, thanks to the apparition of more opened systems, such as Android.

Today, the market of locating services is a commercial sector at growth, supported by big companies, such as Nokia (with its Nokia Maps and other services), Google (with services as Google SMS and Google Maps for Mobile), AOL (with MapQuest) or Ask (with Ask Mobile GPS), among many others. At the same time, on the Web can be found an immense variety of applications focused on services geo-locating and routes guidance, for example GPS navigation services (e.g. amAzeGPS). Research work includes those that combine distinct technologies in order to give a mayor variety of creative applications, for example GiMoDig [15], pedestrian navigational guides [16] and such ones that combine augmented reality techniques with contents from Wikipedia [17], or those that applies these technologies for gaming, as in TikGames site or in [13].

This relevance on these types of applications has motivated the apparition of contests that motive the development of new and creative uses that take advantage of these technologies. NAVTEQ Global LBS Challenge is an annual international contest, sponsored by cellular phone companies, among others; this contest mainly promotes mobile LBS applications, with notable projects and participants such as Atlas Book (www.networksinmotion.com/products/atlasbook.html), Where (www.ulocate.com), Bones in Motion (bonesinmotion.com/corp/index.html), W-PlanIT (www.w-planit.com), 8motions (www.8motions.com), among many others, including applications that take advantage of the social networks for geo-locating purposes, such as loopt (www.loopt.com), reLive! (<http://relive.abmaps.com>), Proxpro (www.proxpro.com), etc. Most of these applications are presented as mashups which integrate geographic information.

3. Mashups

Actually, the use of Web maps that combine information from different sources and gives a more complete user's experience has become common: the so called map mashup. The mashups are a genre of interactive Web applications that enable to retrieve content from external sources and create new services; they are a stamp of the Web 2.0. Mashups are mainly composed of an API / content provider (i.e. Google Maps, MapQuest, among a variety of Web map providers), the Web site in which the mashup is presented and by the client's Web browser; they involve a diverse set of interrelated technologies, they usually use AJAX and Web protocols as SOAP y REST; some other are also related with the use of semantic Web, ontologies and the integration of RSS and ATOM feeds [18].

There are different types of mashups, from videos and photos mashups, until those about sales, searches and news. The case of the digital maps is that they have become a multi purpose centralized tool, used for local business, traffic reports, online dating, among other uses that are related to a specified time and place. The collaborative participation plays an important role in the use of map mashups, as it has been shown in projects such as Wikimapia (www.wikimapia.org) for the collaborative description of world POIs; other case is Tagzania (www.tagzania.com), which is based on the social tagging of places. Considering the previous examples, the map mashups can be used in social searching of places and geo-locatable services in Web maps. This has encouraged the apparition of APIs that facilitate the creation of mashups, such as the ones developed by Google or Yahoo's FireEagle API, which can be used for searching of commercial places, such as restaurants or stores (e.g. Yelp.com site); and there is also the inclusion of geo-location components natively inside Web browsers based on W3C Geolocation Specification [19], which can be used to exploit more similar applications and newer ones. Other initiatives includes WikiMiniAtlas (<http://meta.wikimedia.org/wiki/WikiMiniAtlas>), that includes geo-referential information inside Wikipedia's entrances about geo-locatable places, or the WikiProjekt Georeferenzierung (de.wikipedia.org/wiki/Wikipedia:WikiProjekt_Georeferenzierung/), which uses an alternative based on textual maps. There are also Web 2.0 sites that facilitate the mashup creation to the final users, as MapBuilder (www.mapbuilder.net), meanwhile other more traditional mashups are concerned on the combination of resources from multiple sources, such as GlobalMotion (www.globalmotion.com) or ONGMAP (ongmap.com). Observing this, it can be manifested that there are a lot of information related on geo-location that



can be used on Web maps, and the mashups are a great way to use it.

The activity of the users has become an important part in the operation of the mashups; users can participate actively being volunteers that tag their favorite places or by being consumers of these map mashups geo-location services. However, the social collaboration in relation with the geo-locatable information has a bigger transcendence; this has been indicated in the collaborative geographic information systems.

4. Collaborative GIS

The development of GIS dates back to 60's, with the apparition of GIS as computational tools for capturing, managing and transforming data of spatial references to be used in planning and decision-taking processes. Other work that followed after these, was trying to provide a support for the integration between groups of people and for the decision-taking based on geo-referential data, studying also the impact of them on its users. The development of these systems continued and took advantages of the Internet era, in which the Web maps has a fundamental situation, as is mentioned in [20]; this evolution has been passed to technological issues and the adoption of open standards and the collaborative use inside the social networks [21].

The use of GIS has shown to impulse the capacity of community groups to recognize their necessities, priorities and knowledge. It is in this way that the collaborative GIS appeared. Collaborative GIS are an integration of theories, tools and technologies focused on structuring the human participation on group processes of geospatial-decision. Their objective is to use the argumentation, deliberation, the clear structure of maps and the reconciliation between different groups with representative interests [20].

Meanwhile the Web distribution allows freeing of the spatial barriers in the use of GIS, the use of mobile devices helps in the task of recollecting local data. This integration has helped towards a mobility that allows reaching people and places which under other circumstances could not be considered nor contributed to the spatial information of a GIS. The use of GIS interfaces in the form of thin clients over the Internet has made possible to create maps and the download of spatial information without the need of having to install a complete GIS application. This has changed and made easier the way in which the users access and participate in collaborative planning forums; thanks to this, the users of collaborative maps not only receive geographic information, but also let them actively

contribute in the process, generating a cycle of mutual feedback between the users and the map service.

5. Contextual Information

A context-aware system is a system that considers the context in which is immersed, in order to provide relevant information and services to a user, in which the relevance is defined according the user's task and according to his or her spatial and temporal situation.

There are different senses to define what the context is. For example, on one hand, the context is considered to be all the things that allow to determine a possible set of responses, or on the other hand, context is all the things that are necessary to understand a query; some dictionaries define it as a physical or situational environment, should be political, historical, cultural or from other nature, in which a fact is considered. Nivala [22] considers that context is any information that can be used to characterize the situation of an entity (person, place or object). In his way, Sun [23] indicates that the context includes from *external aspects* from the environment of a person (i.e. geographic physical features, cultural events) to *interior aspects* (personal fitness and healthy).

In this way, the context can be considered as a pervasive element, which has been researched under different focuses of use, e.g. the context modeling for geographical applications [24], for intelligent personalized touristic guides [23] and also for places querying and searching, taking advantage on the use of ontologies [25], [26], [27].

In an application, the context-awareness can be *active* (this is when the application can be adapted automatically to the context in which it is in, this information can be received actively when the user introduces it directly to the application) and can be *passive* (when the application automatically detects the context, giving to the user the decision of accepting or rejecting the options showed by the application).

The same information can be accessed by the users for different purposes and under different contexts; depending on the user, it will be the context of the application. It is for this that ways of identifying different contexts of use for the same information has been searched.

Among the different contexts identified, Nivala shows a classification of types of contexts, based on previous work of Chen & Kotz y Schilit [22]:

Computational context. It considers network connectivity, nearest computer hardware such as printers, etc.

User context. It considers user profile, user location, nearest people, actual social situation.

Physical context. It considers light, noise, traffic, temperature.

Temporal context. It considers the hour, the day of the week, month and year.

Nivala also presents another classification related to types of context, obtained through experimentation with real users. The identified contexts related to mobile map applications were:

Context: Localization. This is defined by the current user location.

Context: System. Hardware features in which a mobile map is used.

Context: Use purpose. It refers to the use that the map is going to have (e.g. purposes for topographic or tourism activities, etc.).

Context: Time. It depends on the moment of the day and the season the user is in.

Context: Physical surrounds. Surroundings physical and topological features.

Context: Navigational history. The blog of use of the user across different geographical areas.

Context: Orientation. It refers to the point the user is viewing at.

Context: Social and cultural features. It includes cultural specific features of each region, i.e. the particular symbology that is used on certain region, the format of dates used, the weight system used, currency, etc.

Context: User. Personal characteristics, as genre, habits, etc.

Another identification of types of contexts is presented in [28], which present broader categories in comparison with the previous one presented:

Environmental context. The time and the weather of the user's location.

User profile. Preferences and tastes from the user that uses the service.

Data profile. It refers to the information related to the geo-locatable services, such as restaurants, hotels, etc; this data is provided by services providers and includes information about schedules, cuisine offered in a restaurant, etc.

The relevance about contextual information on LBS systems relies on the possibility of provide more personalized and elaborated information related to locatable places and services. Inside the LBS systems, the user location in the main component of contextual information and it has the peculiarity that the context in a mobile environment is dynamic. This dynamism causes that the system needs to be constantly adapting, because

the user can frequently change his or her physical location, changing with this the features of his or her surroundings.

Considering the previous, it can be concluded that LBS systems can provide more useful information if they considered the user's profile and other contextual information, in order to obtain more precise and personalized results. This involves a necessity of more sophisticated techniques for the mobile market, which includes a more known and detailed user's profile, with his or her historical, preferences and tastes, which could be matched with the offers that are available from the locatable vendors.

Although adding contextual-awareness to a mobile map application can improve the usability of a map [22], it is still necessary to have more intelligent applications which take advantage of the contextual information, making present the challenge of verifying the semantic relevance of the contextual data. One approach for this is the use of Semantic Web technologies.

6. Semantic Web

The Semantic Web has been presented as an extension of the current Web. It is part of Tim Berners-Lee's vision about the future of the Web; this vision includes having relationships between different information resources, using additional metadata that enable machines to understand and process the information on the Web; however, the traditional Web does not presents the technology to capture the different relationships concerned with the resources.

A bigger step related to the technological evolution was the appearance of XML, which is one of the basic layers of the Semantic Web. However, XML alone is insufficient, because it only provides a syntactic interoperability. Sharing an XML file adds meaning to its content, but only if the publisher and the receiver can identify and understand the named elements that are in it. This makes necessary research to make more intelligent both data and process modeling.

The way in which data is presented to be processed by machines, relies on making the data more intelligent; for this purpose there have been developed languages and technologies just as:

- *RDF (Resource Description Framework)*. This language is used for describing resources (which can be classes or concepts) and its relationships, in the way of triplets. Triplets are composed by three parts: *subject* (the resource that is being described, and it is identified by an URI), *predicate* (the relation existing between a subject and an

object) and an *object* (an object is a resource that is referred or a literal value instead).

- *RDFS (RDF Schema)*. This language allows creating new classes and properties using RDF; with this it is possible to conform hierarchies of classes for the classification and description of resources.

- *OWL (Web Ontology Language)*. Language for the managing of ontologies. An ontology is an explicit specification of a shared conceptualization [29].

- *SPARQL (SPARQL Protocol and RDF Query Language)*. It is a language for querying semantic Web documents.

- *Rule languages*. Rule languages and formats that allow to infer information from other data. A rule specifies an action that is accomplished if certain conditions are fulfilled (*if (x) then y*). Some examples are SWRL (Semantic Web Rule Language) and W3C's RIF (Rule Interchange Format).

Ontologies allow describing and representing in a computer usable way a portion of a mental model about specific domains; they can be used to achieve a major interoperability among different data sources. The use of ontologies on GIS developments allow the interchange of knowledge and the integration of information; for this purpose, ontologies has been used to define common shared vocabularies, for metadata modeling, for defining the meaning of the data across different domains, for data integration, for classifying resources, for information retrieval, among other uses.

The use of ontologies presents a number of advantages related to the integration of geographic information on the Web, such as:

- They allow making queries based on semantic values.
- They provide the availability of having the information represented under different levels of detail.
- They provide a dynamic access to the information.

Some work that denote the relevance of the use of ontologies for managing geographic information is presented in [30], [31]; the ontologies under the geographic information domain has been worked under different approaches, from Web tools for the creation of geographical information domain [32], to projects that consider the description of GIS services and its use for a matchmaking between different ones in order to allow more complex queries [33], [34]. Fonseca [35] considers that if the use of ontologies is part of an active geographic information system, they conform an *Ontology-Driven Geographic Information Systems* (ODGIS), which presents the advantages of having multiple interpretations (roles) of a same geographic feature; this allows to attend different market sectors, for example, considering a concept as *lake*, it can be used under different

circumstances by different geographic information communities: for a department of water studies it is going to be a source of pure water, for a environmental scientist is a wild-life habitat, for a tourist department it is a recreational place, and so on [36].

In order to facilitate the user creation and edition of ontologies, tools as Protégé has appeared; however, there have been appeared new ontology editors that also consider in an innate way the inclusion of georeferential data through Web maps, such as TopBraid Composer.

It is common to find distinct ontologies about the same domain, under a context if not equal, similar. This causes that the use of GIS ontologies shows difficulties due to the peculiarities of this domain, such as the ambiguity of the concepts and the dependent nature on the interpretation and geographical representation of its context. This situation has originated the necessity of establishing a correspondence across the concepts and the relationships between those ontologies. For this purpose, it has been used techniques of matchmaking [37], [38], such as the Normalized Google Distance (NDG) [39].

The selection of the more appropriate vocabularies is a challenge in terms of interoperability; it is because this, that in [40] is recommended the use of terms that come from controlled vocabularies in the form of keyword lists, taxonomies or thesaurus, which can be used to match the data and metadata used in a GIS, improving the quality of the query results.

7. Natural Language for Geo-querying

Human communication is flexible, contextualized and full of vagueness and ambiguity. Humans speak and think about spatial relations in an imprecise way, using vague and probabilistic concepts; the people queries and orients in a qualitative mean, not in a quantitative mean [10], meanwhile computers use languages with a well defined semantic and grammar for their communication.

The use of spatial relations in natural language gives to GIS users more alternatives to formulate their queries, according to their task in which they are using a system. The qualitative models can contribute to a broader user of GIS technology.

The real world entities that are represented on a geographical database are corresponded to dots, lines and areas. Generally, geospatial queries include a symbolic representation of the spatial relations, instead of a detailed geometric description; some of these spatial relation models in natural language are present on [10] and [41]:

Linguistic models. They are based on introspection, but they present a lack of mathematical objectivity which difficult its use on an information system.

Geometric models. These models are oriented towards a quantitative spatial location.

Connectionistic approaches. Model has have its basis on the human brain to do parallel computing; it involves training a model using a set of detailed geometric configurations.

9-intersection model. This is a topological model, which can be based on cardinal directions or approximated distances.

Based on GIS literature, there are different types of common spatial relations, such as:

Topological relations. These are spatial relations that do not vary under continuous transformations.

Metric relations. These refer to those relations about distance, which can be quantitative if the distance can be sized or qualitative if the distance is described as near or far.

Relations of direction. These makes reference to azimuth, which is quantitative; it also refer to the description of directions in a way such as forward, to the right or to the west, which are qualitative directions.

In order to create formalisms about natural language spatial relations, it is necessary to do a matching between the symbolic representations of the real world spatial relationships, towards a valid geometric configuration.

Natural language has a limited set of words that can be used to describe an infinite number of geometric configurations that can be built. For example, in despite the geometry of a set of configurations which show the path of a way over a park (symbolized has a line and a polygonal shape, respectively), it is possible to have different paths that are different but people would use the same terms to describe these different configurations (i.e. a path across the park, but inside the park there could be different paths that cross it). On the other hand, different terms can be used to describe the same configuration, also if the topology of these configurations is the same (i.e. different people can describe the same path using different terms and expressions).

The use of prepositions in order to define spatial relations is subjected to complex and hidden rules [42]; the spatial relations defined by a natural language are context dependant, i.e. the meaning of *near* is imprecise and depends on the scale that is used, on factors as the geographic region, the moment and place, the task that is performed as well as personal characteristics [43].

Querying for geographical information of places and services can become a difficult task because the implicit problems of having to express which is the desired information to the system. It is because this that different means of querying has been searched, not depending only on a standard textual entrance. It is in this way that the interaction between users and computers relays on the entrances that the firsts give to the machines, letting them express spatial relations with vague terms through natural language queries from mobile devices [44] or through dialogue based systems [45]. Another approach is the use of multi modal interfaces for geographic information related systems; among these, there have been some that have considered spoken entrances and spoken guidance [46], the use of sketches in which a user draws his or her location, such as the ones described on [47] and [48]; other attempts include the use of visual languages [49], [50] and the use of augmented reality technologies [51].

8. Case of Study Prototype

A prototype for locating restaurants which considers contextual-awareness and Semantic Web technologies was developed. Data from Chefmoz repository (<http://chefmoz.org/>) was used; this data is maintained by the social collaborative effort of people across the world. The prototype considers the management of users' and geo-located services' profiles through ontologies for a more pertinent and personalized information retrieval of geo-located places, matching user and services features, in other words, for this case, the goal was matching personal profiles and Chefmoz restaurants' data, considering the personal, spatial and temporal contextual domains of a query.

A process of reverse geocoding over each restaurant described on Chefmoz data was applied, using Google Maps' geocodification functions. This was because Chefmoz data includes the address of each restaurant in it, but it doesn't have geospatial information about latitude and longitude coordinates, which are used to locate a point over a Web map.

An ontological vocabulary focused on representing the user's preferences, including user's characteristics and cuisine preferences was applied as an extension inside the FOAF vocabulary; FOAF is a well known vocabulary that allows describing main data of a user and his or her friends. By adding the proposed vocabulary extension, is a way to show the scalability that the Semantic Web allows.

The user location is obtained from a Web map (if this information was not included in the extension of the user's FOAF file). Until this point, the nearest restaurants to a



user specified position can be located, but it is also necessary to determine which of these results are the more pertinent considering the user's preferences.

The contextual models taken into account for this approach include:

-*Service model*. Describes restaurants' specific details.

-*User model*. Describes the user profile.

-*Environment model*. Specifies the state of the elements that surround a user, such as date, hour and weather.

The main concepts taken from Chefmoz that could be used for matching the user model and the environment model are: cuisine, alcohol, smoking, dress, recommended dishes, accepts (type of payment), parking, hours, accessibility and price; these concepts and its respective relationships are used for a restaurant domain ontology. The resulting restaurant ontology is formed from Chefmoz concepts and other domain ontologies found through Swoogle search machine. This ontology is used to represent the service model.

Then, the user model is matched with the restaurant data, using SPARQL queries, in order to find the more accurate restaurants that match with the spatial and personal context of a user, in other words, a matching between the Chefmoz data and the FOAF user file is done.

Until the previous steps, a set of restaurants have been retrieved considering the location and some user's preferences; however, in order to obtain more accurate results, the use of semantic rules can be applied. With these, other contextual information can be matched, according to special situations, e.g. considering the weather (from the environment context) a desirable feature would be expected from the restaurants retrieved (if it is raining, then return restaurants that have under roof characteristic). The idea behind this is also to have a scalable mean for adding and extending more rules; so, according to the values obtained from the context, there are going to be rules that are going to be selected. The language used for applying semantic rules was Semantic Web Rule Language (SWRL) implementation included in Protégé ontology editor; for obtaining a set of results after applying the rules, Semantic Query Web Rule Language (SQWRL) was also used.

For the application of the rules it was necessary to retrieve environment information. For the environment model some Web services that provide information about the weather and the current hour of a particular place have been used. This data is obtained from the latitude and longitude in which user is in; in this way it could be possible to provide relevant results according to the

moment a query is made, considering for example the opening and closing hours of a restaurant. Another characteristic related with the personal context is the role that a person is having at the moment of the query, roles as if the person is with his or her family, if he or she is in a business trip and so on.

Finally, FreeLing (a part-of-speech tagger) was used for receiving the input entrance in natural language; after receiving the input, FreeLing identifies the nouns and verbs of the entrance, and using a mediator ontology with a controlled vocabulary (which considers the terms presented on Chefmoz) the query is matched with the restaurant ontology. With this process is possible to determine the information that is desired from the service model.

A resume of the steps explained in this section can be observed on Fig. 1. As future work on this prototype, it is the adding of more rules, the adding of more terms to the controlled vocabulary used for the FreeLing natural language process; finally the prototype is going to be tested with real users.

4. Conclusions

The continuous and dynamic changes on the technology adoption by the society have turned the different technological uses of geographic information and applications a crucial component for the decision-taking, inclusive on particular issues, such as the election of the nearest restaurants that provides the most according features against the user preferences.

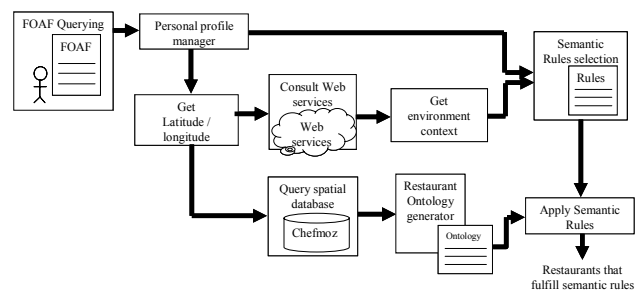


Fig. 1 Steps considered for a prototype that integrates context-awareness, Semantic Web technologies and data obtained from Chefmoz collaborative project, in order to locate the more accurate and personalized selection of restaurants for a user.

The combination of different data sets, for example through mashups, coincides with the essence of the Semantic Web; however, the Semantic Web provides of more consistent models and tools used to define and use

the implicit relationships among the data on the Web, and as well as the Web 2.0, a more intelligent share of information is desired.

Thanks to the use of social networks and collaborative participation have been appeared geo-social networks that interact with digital map services and organize the social collaboration among the users and their geographical locations, an example of this is the Chefmoz project.

The availability of semantically annotated data is crucial, such as the Chefmoz project; it is possible to apply a collaborative perspective as a data source of information. However, in our practice, although Chefmoz has a variety of annotated information, it presents several bugs, making its processing a slowly but no impossible task.

The consideration of semantically contextual data can be used in order to improve the precision of the retrieved results for geo-location queries. It can be seen that the next generation of geospatial applications should combine real world knowledge with space and time context, bringing more precise and personalized geo-location retrieval systems.

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Domain Decomposition Based High Performance Parallel Computing

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Abstract

The study deals with the parallelization of finite element based Navier-Stokes codes using domain decomposition and state-of-art sparse direct solvers. There has been significant improvement in the performance of sparse direct solvers. Parallel sparse direct solvers are not found to exhibit good scalability. Hence, the parallelization of sparse direct solvers is done using domain decomposition techniques. A highly efficient sparse direct solver PARDISO is used in this study. The scalability of both Newton and modified Newton algorithms are tested.

Key words: *finite element, PARDISO solver, distributed computing, domain decomposition, Newton method.*

1. Introduction

Three dimensional finite element problems pose severe limitations in terms of computational time and memory requirement. The choice of a direct solver or an iterative solver for large problems is not trivial. Iterative solvers are considered to be highly memory efficient, especially for larger problems. However, it is observed that the choice of an iterative solver is highly problem specific. For problems involving highly ill conditioned matrices, iterative solvers do not perform well. Direct solvers on the other hand are considered to be very robust and problem independent. However, they are seriously limited by large memory requirements. Memory issue for direct solvers is being addressed through several ways. The advent of multifrontal solvers [1] coupled with highly efficient ordering techniques has greatly increased the computational efficiency and reduced the memory requirement for direct solvers. The superior performance of Multifrontal solvers has been successfully demonstrated both in the context of finite volume problems [2-4], finite element problems [5-6] and in power system simulations

[7-9]. For three dimensional problems the memory requirement is still a limitation for larger problems. To circumvent this problem, a 64-bit machine with a larger RAM can be used for computation, an out-of-core sparse direct solvers can be used which have the capability of storing the factors on the disk during factorization or the direct solvers can be used in a distributed computing environment. This paper specifically deals with the application of sparse direct solvers in a distributed computing environment.

Recently a parallel direct solver, Multifrontal Massively Parallel Solver (MUMPS) [10-12] in a distributed environment [6] has been studied for both two dimensional and three dimensional problems. It has been reported that by using MUMPS solver, larger problems can be solved in a parallel environment as the memory is distributed amongst the different processors. However it has also been reported that the scalability of MUMPS solver [6] is not very high. In order to obtain good scalability, instead of using a parallel sparse direct solver, the problem itself is split amongst the different processors using domain decomposition [13] and a highly efficient sparse direct solver is used in each of subdomain problems. An efficient sparse direct solver PARDISO [14-16] is being used in this study.

Laminar flow through a rectangular channel has been chosen as a benchmark problem for studying the scalability of domain decomposition techniques in a distributed environment. The system of non-linear equations obtained from the discretization of Navier-Stokes equations is solved using Newton's method. The system of linear equations obtained during each Newton iteration is solved in parallel using additive Schwarz domain decomposition algorithm [13]. The grid is divided

into many overlapping subdomains (equal to the number of processors being used) and each processor solves its local subdomain problem using an efficient sparse direct solver. Figure 1 shows a typical overlapping subdomain for additive Schwarz algorithm. In additive Schwarz algorithm, the values at the interfaces are updated only after a complete cycle of subdomain solution is computed. In using direct solvers, factorization of the left hand side matrix is the most time consuming step. To avoid repeated factorization in the subdomains, advantage is taken of the resolution facility of the direct solvers (i.e. the previously computed LU factors are reused in the solve phase). A modified version of the additive Schwarz algorithm is also proposed which is computationally very efficient.

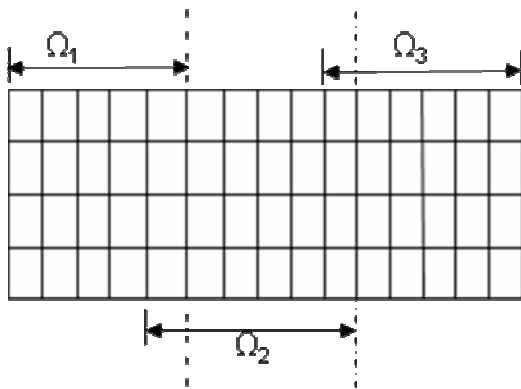


Figure 1: Typical overlapping subdomain division for additive Schwarz algorithm

2. Mathematical Formulation

The governing equations for laminar flow through a three-dimensional rectangular duct [6] are presented below in the non-dimensional form. In three-dimensional calculations, instead of the primitive u, v, w formulation, penalty approach is used to reduce the memory requirements.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0, \tag{1}$$

$$\begin{aligned} \frac{\partial}{\partial x}(u^2) + \frac{\partial}{\partial y}(uv) + \frac{\partial}{\partial z}(uw) = \lambda \frac{\partial}{\partial x} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) + \frac{\partial}{\partial x} \left(\frac{2}{\text{Re}} \frac{\partial u}{\partial x} \right) \\ + \frac{\partial}{\partial y} \left(\frac{1}{\text{Re}} \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right) + \frac{\partial}{\partial z} \left(\frac{1}{\text{Re}} \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right) \right), \end{aligned} \tag{2}$$

$$\begin{aligned} \frac{\partial}{\partial x}(uv) + \frac{\partial}{\partial y}(v^2) + \frac{\partial}{\partial z}(vw) = \lambda \frac{\partial}{\partial y} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) + \frac{\partial}{\partial x} \left(\frac{1}{\text{Re}} \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right) \\ + \frac{\partial}{\partial y} \left(\frac{2}{\text{Re}} \frac{\partial v}{\partial y} \right) + \frac{\partial}{\partial z} \left(\frac{1}{\text{Re}} \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right) \right), \end{aligned} \tag{3}$$

and

$$\begin{aligned} \frac{\partial}{\partial x}(uw) + \frac{\partial}{\partial y}(vw) + \frac{\partial}{\partial z}(w^2) = \lambda \frac{\partial}{\partial z} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) + \frac{\partial}{\partial x} \left(\frac{1}{\text{Re}} \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right) \right) \\ + \frac{\partial}{\partial y} \left(\frac{1}{\text{Re}} \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right) \right) + \frac{\partial}{\partial z} \left(\frac{2}{\text{Re}} \frac{\partial w}{\partial z} \right). \end{aligned} \tag{4}$$

where u, v, w are the x, y and z components of velocity, the bulk flow Reynolds number, $Re = \rho U_0 D / \mu$, U_0 being the inlet velocity, ρ the density, L the channel length, μ is the dynamic viscosity and λ is the penalty parameter. Velocities are non-dimensionalized with respect to U_0 .

The boundary conditions are prescribed as follows:

(1) Along the channel inlet:

$$u = 1; v = 0; w = 0. \tag{5}$$

(2) Along the channel exit:

$$\frac{\partial u}{\partial x} = 0; \frac{\partial v}{\partial x} = 0; \frac{\partial w}{\partial x} = 0. \tag{6}$$

(3) Along the walls:

$$u = 0; v = 0; w = 0. \tag{7}$$

3. Newton's Algorithm

The above set of differential equations (Eq. 1-4) is discretized using Galerkin finite element formulation (GFEM). This results in a set of non-linear equations which is solved using Newton's iterative algorithm.

Let $\underline{X}^{(k)}$ be the available vector of field unknowns for the $(k+1)^{\text{th}}$ iteration. Then the update is obtained as

$$\underline{X}^{(k+1)} = \underline{X}^{(k)} + \alpha \delta \underline{X}^{(k)}, \tag{8}$$

where α is an under-relaxation factor, and $\delta \underline{X}^{(k)}$ is the correction vector obtained by solving the linearized system

$$[J]^{(k)} \{ \delta \underline{X}^{(k)} \} = -\{ F \}^{(k)}. \tag{9}$$

Here, $[J]$ is the Jacobian matrix,

$$[J]^{(k)} = \frac{\partial F^{(k)}}{\partial \underline{X}^{(k)}}. \tag{10}$$

and $\{F\}^{(k)}$ is the residual vector. Newton's iteration is continued till the infinity norm of the correction vector $\delta X^{(k)}$ converges to a prescribed tolerance of 10^{-6} .

4. Domain Decomposition

The solution of linear equations (Eq. 9) resulting during each Newton step is the most time consuming time step. It is both computationally expensive and memory consuming. To handle the computational burden, Eq. (9) is solved in a parallel distributed environment using additive Schwarz domain decomposition technique. The domain is split into approximately equal size (similar to Figure 1) subdomains (equal to the number of processors) and distributed amongst the different processors. Each processor solves its own subdomain problem. The partitioning of the domain into subdomains is done by using METIS [17] partitioning routine. The additive Schwarz procedure [13] is similar to the block-Jacobi iteration and consists of updating all the block components from the same residual. The basic additive Schwarz iteration is given below in brief.

1. $A = J^{(k)}$; $b = F^{(k)}$; $p = \delta X^{(k)}$
2. For $i = 1, \dots, s$
3. $\delta_i = R_i^T A_i^{-1} R_i (b - Ap)$
4. Enddo
5. $p_{new} = p + \alpha \sum_{i=1}^s \delta_i$

(11)

Here R_i is the restriction operator, which restricts a given vector of global domain Ω to a local subdomain Ω_i . R_i^T is a prolongation operator which takes a variable from local subdomain Ω_i to global domain Ω . Each instance of the loop redefines different components of the new approximation and there is no data dependency between the subproblems involved in the loop. Each subproblem is solved on a different processor. Instead of solving the whole problem (eq. 9) on a single processor, the problem is divided into subdomain problems (step 3 of eq. 11) which each processor can solve independently. Each subdomain problem is solved using an efficient sparse direct solver, PARDISO. α is the under-relaxation factor. The value of under-relaxation factor is chosen as 1 for updating all variables at the interior nodes of the subdomain and 0.6 for updating the variables at the subdomain interface nodes. The system is solved using two iteration loops. The first is the outer Newton iterative loop and the second is the inner iterative loop for solving the system of linear equations (Eq. 9) using additive Schwarz algorithm (Eq. 11). This algorithm is being

referred to in this paper as Newton based additive Schwarz algorithm (NAS).

To improve the computational efficiency of the NAS algorithm, a modified Newton based additive Schwarz algorithm (MNAS) is proposed. The algorithm is presented below.

1. $A = J^{(k)}$; $A^0 = J^{(0)}$; $b = F^{(k)}$; $p = \delta X^{(k)}$
2. For $i = 1, \dots, s$
3. $\delta_i = R_i^T (A^0)_i^{-1} R_i (b - Ap)$
4. Enddo
5. $p_{new} = p + \alpha \sum_{i=1}^s \delta_i$

(12)

In essence, it solves the same system of equations as the NAS algorithm, since A and b are the same. Consequently the quadratic Newton convergence is retained. The difference is that the step 3 of additive Schwarz iterative loop uses a different left hand side matrix. The subdomains do not update the left hand side matrix during Newton iterations. It uses the same matrix that was generated during the first Newton iteration. The advantage with that is that the LU factors are computed (most time consuming step) only once and are repeatedly reused for all the inner and the outer iterative loops. This will increase the number of inner additive Schwarz iterations but nevertheless saves computational time.

5. PARDISO Solver

PARDISO package (part of Intel MKL library) is a high-performance, robust, memory efficient and easy to use software for solving large sparse symmetric and unsymmetric linear systems. The solver uses a combination of left- and right-looking Level-3 BLAS supernode techniques. PARDISO uses a Level-3 BLAS update and pipelining with a combination of left- and right-looking supernode techniques [14-16]. Unsymmetric permutation of rows is used to place large matrix entries on the diagonal. Complete block diagonal supernode pivoting allows dynamical interchanges of columns and rows during the factorization process. The level-3 BLAS efficiency is retained and an advanced two-level left-right looking scheduling scheme is used to achieve higher efficiency. The goal is to preprocess the coefficient matrix A so as to obtain an equivalent system with a matrix that is better scaled and more diagonally dominant. This preprocessing reduces the need for partial pivoting, thereby speeding up the factorization process. METIS and Minimum degree ordering options are available within the solver.

6. Numerical Implementation

The solution of non-linear system of equations involves two iterative loops. One is the outer Newton's iterative loop (outer loop) and the other is the inner additive Schwarz domain decomposition loop (inner loop) to solve the linear system of equations (Eq. 9) simultaneously on different processors. Each subdomain problem in the inner loop is solved by a direct solver. Since the left hand matrix is not updated during the inner iterations, the resolution facility of direct solvers can be used to skip the factorization phase (i.e. only the solve phase is invoked). The inner iterations are continued till the error norm is within tolerance. In the outer iterative loop for Newton, the Jacobian is updated. Hence the factorization phase is invoked in each of the subdomain during the first inner iteration of all outer iterations. In the case of modified Newton, the Jacobian is not updated during the outer iterations. Consequently, the subdomains need not invoke the factorization phase during the first inner iteration loop of all the outer iterations. In summary, for the modified Newton algorithm, each of the subdomains perform *LU* factorization only once and all other subsequent calls to the solver invokes only the solve phase. In the case of Newton algorithm, each of the subdomains invokes the *LU* factorization during the first inner iteration of all the outer iterations. The performance of both Newton and modified Newton are examined in this paper. All the simulations are carried out on Ohio Supercomputing Cluster "Glenn". It is a cluster of AMD opteron multi-core, 2.6 GHZ, 8GB RAM machines.

7. Results and Discussion

Preliminary experiments have shown that METIS ordering performs better in terms of computational time and memory requirements. Hence METIS is used for ordering the entries of the matrix. Table 1 shows the comparison of CPU times and memory requirement for solving a 100x20x20 mesh on two processors for minimum degree (MD) and METIS ordering. In table 1, dof refers to the number of degrees of freedom (or the total number of equations). Results indicate that METIS performs much better than the minimum degree algorithm. Based on this observation, METIS ordering is used for all subsequent calculations.

Table 1 Performance of different orderings for PARDISO solver for a 100x20x20 mesh on 2 processors

Ordering	#dof's	CPU time (sec)	Memory (GB)
MD	44541	602	5.3

METIS	44541	178	1.6

Figure 2 shows the performance of NAS and NMAS algorithms on 2 processors for a 100x20x20 grid. The convergence rates of both the algorithms show Newton quadratic convergence. The residual norm is exactly similar for both the algorithms. The Newton based additive Schwarz algorithm takes 178 seconds and Modified Newton based additive Schwarz algorithm takes 87 seconds for full convergence. The time taken for the first Newton iteration is the same for both the algorithms but NMAS algorithms takes much lesser time for the subsequent iterations.

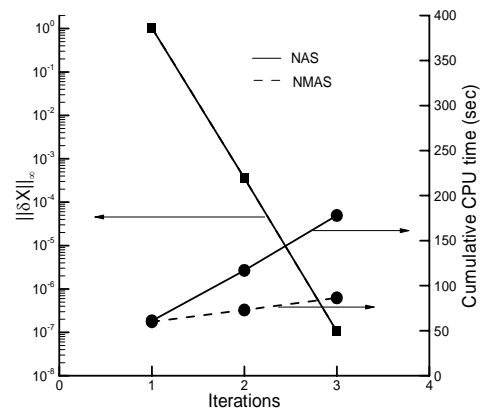


Figure 2: Comparison of CPU time and residual norm for NAS and NMAS algorithms for 100x20x20 grid on 2 processors.

Table 2 shows the performance of NAS and MNAS algorithms as a function of the number of processors. Excellent scalability is observed both for NAS and MNAS algorithms. For increase of processors from 2 to 12, the computational time reduced by a factor of 12.7 for NAS and a factor of 7.9 for MNAS algorithm. Figure 3 shows the pictorial representation of the scalability performance of the NAS and MNAS algorithms. Up to 8 processors, the scalability is good and beyond that the scalability decreases. For larger grids, it may be possible to obtain good scalability even beyond 8 processors. Note that the memory requirement for both the NAS and MNAS algorithms are exactly the same, since the size of the *LU* factors remain the same. It is observed that by increasing the number of processors from 2 to 12, the memory requirement on a single processor reduced by a factor of 11. Hence domain decomposition techniques are highly memory efficient. Unlike the use of a distributed parallel direct solver like MUMPS [6], the scalability of domain decomposition method is quite high. By using distributed

computing using domain decomposition algorithm, relatively much larger problems can be solved. The memory limitation of direct solvers can be well addressed using domain decomposition technique by running the problem on a large number of processors.

Table 2: Comparison of the performance of NAS and MNAS for a 100x20x20 mesh

# of processors	NAS CPU time (sec)	MNAS CPU time (sec)	max memory on one processor (MB)
2	178	87	685
4	65.8	35.1	282
6	41	22	157
8	26	15	116
10	19	12	88
12	14	11	62

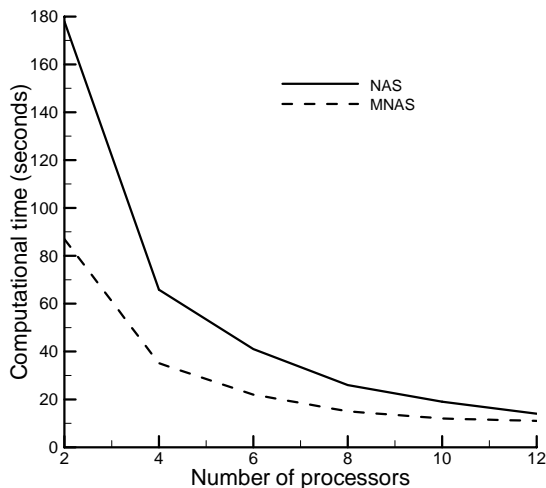


Figure 3: Scalability performance of NAS and MNAS on a 100x20x20 mesh

8. Conclusions

Distributed parallel computing of finite element Navier-Stokes code using additive Schwarz algorithm is demonstrated. An efficient sparse direct solver PARDISO is used for solving the subdomain problems. Two algorithms NAS and MNAS have been explored. It is observed that the MNAS algorithm can lead to significant savings in computational time. The additive Schwarz algorithm is found to scale well both in terms of computational time and memory requirement. It could of great value in large scale three dimensional computations.

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Multi-Agent System Interaction in Integrated SCM

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Abstract

Coordination between organizations on strategic, tactical and operation levels leads to more effective and efficient supply chains. Supply chain management is increasing day by day in modern enterprises.. The environment is becoming competitive and many enterprises will find it difficult to survive if they do not make their sourcing, production and distribution more efficient. Multi-agent supply chain management has recognized as an effective methodology for supply chain management. Multi-agent systems (MAS) offer new methods compared to conventional, centrally organized architectures in the scope of supply chain management (SCM). Since necessary data are not available within the whole supply chain, an integrated approach for production planning and control taking into account all the partners involved is not feasible. In this study we show how MAS architecture interacts in the integrated SCM architecture with the help of various intelligent agents to highlight the above problem.

Keywords: *Supply Chain management (SCM), Processing Management, Multi agent system (MAS), Bullwhip effect.*

1. Introduction

Inter-enterprise collaboration is highly challenged and supply chain management (SCM) is one of such strategies through which individual enterprises form partnerships and achieve inter-enterprise collaboration. A supply chain comprises multiple enterprises to collaboratively provide customers with products or services. SCM is the relationship across the supply chain. Multi-agent system (MAS) has

been recognized as a promising technology for the automation of SCM in recent years.

The goal of this paper is to introduce a new supply chain planning, execution and control approach with the help of multi-agent systems that perform both inter- and intra-organizational planning and execution tasks are an important

innovation. Supply chains consist of networks formed by co-operating partners that are covering various companies (Original Equipment manufacturers (OEM), suppliers, sub-suppliers, etc.). Due to Bullwhip effect of fluctuations in market, the global optimization of the corresponding business processes offers a vast optimization potential. That hampered by the fact that the companies are not willing to reveal their production data to competitors, unless they are forced to do so. due to which a global optimization is hardly feasible today. That's why MAS perfectly suit these demands for global flexibility, co-operation and local autonomy. The individual projects that are involved in the research activities presented in this paper[1][3][4][6] address these problems and offer services in the range of SCM scheduling. In this paper, a reference model integrating the mentioned MAS is introduced including interfaces and gateways between the systems.

1.1 SCM Integrated Architecture

The basic scenario is to introduce the reference model comprises a simplified supply chain of a manufacturer of automobile equipment (see figure 1). Its main value to assemble the parts from different suppliers. In this scenario, a manufacture of automobile components and a supplier of tyres are incorporated. The logistics service providers are necessary to deliver the parts to the producer and to its customers.[2][7].

The complexity of managing supply chains results in many different interdependent tasks such as the planning, execution and controlling of production, routing, logistics and inventory processes. The basic scenario focuses on production processes with the help of integration between multiple MAS. Table 1 gives an

overview on the various functionality of each MAS involved

The distributed global planning of supply chain activities achieved with the help of DISPOWEB[3] system that generates an initial plan of orders and suborders concerning prices and time-points of delivery, and after that software agents located at the different supply chain partners carry on negotiations[13]. (In Fig 2) We have shown the interaction in integrated architecture with the help of MAS.

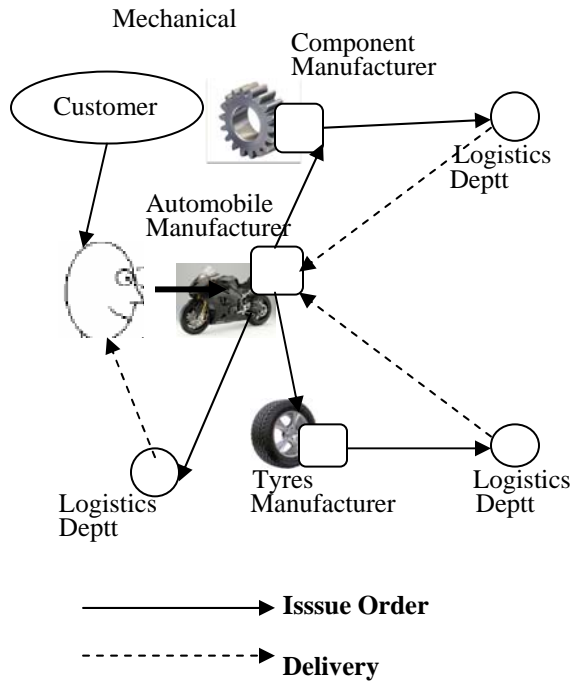


Fig 1. Scenario of SCM

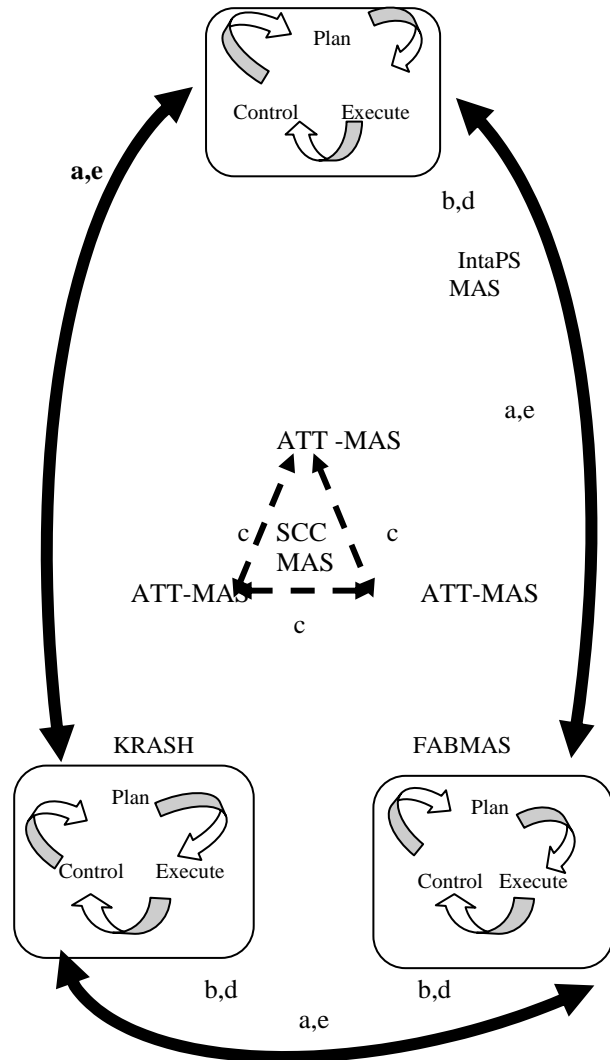
Table 1. Overview of MAS functionality

Main Functionality	Project
Negotiations between enterprises	DISPOWEB
Integrated process planning and scheduling (with focus on discrete manufacturing)	IntaPS
Production planning and controlling (with focus on assembling industries)	KRASH
Production planning and controlling (with focus on batch production)	FABMAS
Operational tracking of orders including suborders in supply chains	ATT*
Analysis of historical tracking information (tracing)	SCC*

* ATT and SCC are conducted in one project

- Firstly supply chain partners optimize the cost and due date of deliveries which are used in each enterprise at intra-level to plan the production of goods in SCM (a).

- For production planning three multi agent systems are concerned in which input are required from the DISPOWEB[3] agents for production facilities (b).
- Thirdly there are ATT/SCC*[1] project that monitor the orders on every stage of supply chain using a distributed architecture. In case of event that endanger the planned fulfillment. The ATT* system communicates with the partner of enterprise to inform about the endangerment(c)[14].
- Fourthly if such type of event occur in an enterprise than the output comes from ATT* system is used to reschedule the process planning to overcome such danger events in future (d). DISPOWEB MAS



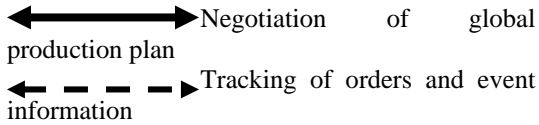


Fig.2 Architecture of MAS in integrated SCM

- In case of such a major events, renegotiation of the contracts at the inter-enterprise level occurs (e). Finally the ATT* system communicate with trusted third party service called SCC* MAS analyze history of orders & their sub-orders due to which we identify the pattern in supply chain orders that leads to the hindrances during fulfillment of planning.

2. Database Structure in Integrated SCM

The data structure is a significant component of the presented approach and serves as a basis for workflow integration within the supply chain scenario. The data structure is used both for the intra- and inter-organizational production planning. In the case of intra-organizational planning tasks, the order data serve as dynamic input to the planning process[11]. The bill of materialist analyzed and, taking into account the operations another parameters like the lot size or due dates, partial orders are assigned to single production cells. [16].

MAS-based planning algorithms perform the planning process within the projects mentioned in the first chapter [12]. In the inter-organizational case, order data and estimated completion dates are exchanged between the partners to realize an integrated production planning. The DISPOWEB agents need information about the load situation and completion times from the particular intra-organizational agents. The ATT systems are triggered with the information derived from the planning processes and then begin to gather information of the monitored orders (e.g. milestones, event data) [15].



Fig.3 Database Structure

3. Integrated SCM Scheduling

To enable the accomplishment of production plan comprising the whole supply chain, we will use the concept of supply chain scheduling where each firm has to be represented by each firm as shown in fig.3.

- The production plan is initiated by occurrence of order (1).
- The DISPOWEB agent requests the KRASH agent for processing time & related cost for particular manufacturing process (2).
- After getting the task load information from KRASH [6] agent, the DISPOWEB agent begins the formulate the set of feasible scenarios (3).
- The best possible scenario with latest possible time is computed & submitted to DISPOWEB agent (4)

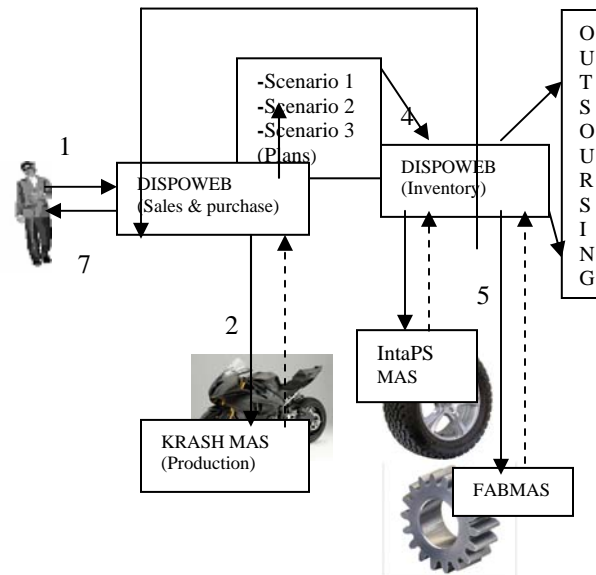


Fig 4. Supply Chain Scheduling with MAS

- This best scenario is further moved to other suppliers i.e. FABMAS [4] & IntaPS MAS for delivery of required input products through DISPOWEB agent (5).
- The DISPOWEB agent get the information from other agents that are not depend on other suppliers can fulfill the demand by submitting a supply vector consist of production cost & load situation for required sources to the final DISPOWEB agent (6).
- Finally the DISPOWEB agent computes the most profitable time for job execution is computed & dispatches the job by transmitting the selected delivery time to supplier agent, implying the closing of delivery contract between the parties. At last can contract to the consumer (7).

4. Achievements of MAS in Integrated SCM Architecture

The goal of the integrated SCM architecture is the co-ordination of the PPC (Production Planning and Control) activities throughout the whole logistics chain to realize a global monetary optimization. With the concept of database structure we can easily explore, extract, transform and deliver the data to anywhere at any time and frequency. With the help of various projects like DISPOWEB, FABMAS, KRASH, Inta-PS we create a successful production plan with the help of different multi agents that can interact with each other without any human intervention.

5. Conclusion

To compete in today's business environment, companies are required to integrate business activities into a global response strategy. To cope with sudden changes, companies need to conduct their business activities in a flexible manner. MAS is promised a solution framework for SCM because of the effective interaction between agents through an agent communication language. The integration of systems and technology also enables the reengineering of the business processes by leveraging technological capabilities that were previously unavailable. In this paper we show how MAS architecture interacts in the integrated SCM architecture with the help of various intelligent agents to highlight the above problem [8]. It addresses the

architectural, the planning and the execution aspects of supply chain management. The goal of the evaluations is to prove the feasibility of the approach and gather first experiences and results [9]. In the next step, the system is evaluated using a real test case scenario that represents an industrial scope and the corresponding complexity. One instantiation of the database structure presented The supply chain that was chosen represents automobile manufacturer and its suppliers [5][10].

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Enhanced Trustworthy and High-Quality Information Retrieval System for Web Search Engines

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Abstract

The WWW is the most important source of information. But, there is no guarantee for information correctness and lots of conflicting information is retrieved by the search engines and the quality of provided information also varies from low quality to high quality. We provide enhanced trustworthiness in both specific (entity) and broad (content) queries in web searching. The filtering of trustworthiness is based on 5 factors – Provenance, Authority, Age, Popularity, and Related Links. The trustworthiness is calculated based on these 5 factors and it is stored thereby increasing the performance in retrieving trustworthy websites. The calculated trustworthiness is stored only for static websites. Quality is provided based on policies selected by the user. Quality based ranking of retrieved trusted information is provided using WIQA (Web Information Quality Assessment) Framework.

Keywords: Search Engines, Trustworthiness, High-Quality, WIQA

1. Introduction

Information comes from increasingly diverse sources of varying quality. There is no guarantee for the correctness of information on the Web. Also, different websites often provide conflicting information [8], as shown in the following example.

Example: (Runtime of Harry Potter 6 movie)

The user gives an input query as “Harry Potter 6 runtime” in the Google Search Engine. The information retrieved is as follows: 8 websites gave the information as 153 mins, 7 websites as 138 mins, 2 websites as 144 mins, 1 website each as 94 mins and 104 mins. Thus it is clear that the search results are not correlative and credible [9].

Information quality is task-dependent. A user might consider the quality of a piece of information appropriate for one task but not sufficient for another task. Information quality is subjective, as a second less quality concerned user might consider the quality of the same piece of information appropriate for both tasks. Which quality dimensions are relevant and which levels of quality are required for each dimension is determined by the specific task at hand and the subjective preferences of the information consumer.

2. Related Works

A framework for the Veracity problem is given in [1] i.e., Conformity to truth, which studies how to find true facts from a large amount of conflicting information on many subjects that is provided by various websites. This framework helps us to find trustable websites and true facts. An algorithm called TRUTHFINDER is existing in [1] for the Veracity problem, which utilizes the relationships between websites and their information. A website is trustworthy if it provides many pieces of true information and a piece of information is likely to be true if it is provided by many trustworthy websites. An iterative method is used to infer the trustworthiness of websites and the correctness of information from each other. For selecting trustworthy information, the TRUTHFINDER uses two parameters – Website trustworthiness and Fact confidence. The limitations in TRUTHFINDER are that, the initial assumption of Website Trustworthiness is taken as 0.9 in all cases like popular, authoritative and untrustworthy websites. Only for specific queries (entities) trustworthy websites are retrieved based on single object or property (EX: height of Mt.Everest). Also, Recalculation of trustworthiness of websites for each query given by the user reduces the performance of the system.

The quality of the search results from the web search engines varies as information providers have different levels of knowledge and different intentions [2]. Users of web-based systems are therefore confronted with the increasingly difficult task of selecting high quality information from the vast amount of web-accessible information. In this existing work, the authors introduce the WIQA—Information Quality Assessment Framework. The framework enables information consumers to apply a wide range of policies to filter information. The framework employs the Named Graphs data model for the representation of information together with quality related meta-information. The framework uses the WIQA-PL policy language for expressing information filtering policies against this data model. WIQA-PL policies are expressed in the form of graph patterns and filter conditions. The WIQA framework is incorporated into an application called WIQA browser. Implementing this framework in search engines personalizes

the web search and helps in the retrieval of high quality information [3]. This is not done in the existing work.

AQUAINT relies heavily on the detection and analysis of design aspects in order to distinguish high quality from low quality pages [6]. But this paper uses subjective policy selection method to assess the quality of the web page.

3. Proposed work

In the retrieval of Trustworthy and High-Quality information from web search engines, this paper deals with having Content-Trust in the retrieved web search results.

Content-trust in broad queries based on factors like [5]

- Authority – domain specific,
- Related resources – links from trusted websites
- Popularity- most visited websites,
- Provenance - origin of information provider
- Age - lifespan of time-dependent information

To clear out the assumption made by the TRUTHFINDER, the provenance information about the various websites is used and the initial website trustworthiness is calculated accordingly. The WIQA framework is implemented in web search engines for retrieval of High-Quality and Trustworthy information. Recalculation of website trustworthiness for each query given by the user reduces the performance of the search engine. Hence a method to store the recently calculated trustworthiness in files is provided to improve the search engine's performance [4]. This method is followed only for static websites. Since the content of web 2.0 sites are subject to frequent changes by the users, trustworthiness is not stored in the case of web 2.0 sites.

4. Architecture

The proposed overall architecture for the Trustworthy and High-Quality Information Retrieval System for web search engines is given in the following figure – Fig.1.

The user gives the search query in the web search engine interface and also chooses from the various quality policies provided. The search query is given to the searcher which fetches the result URLs from the database.

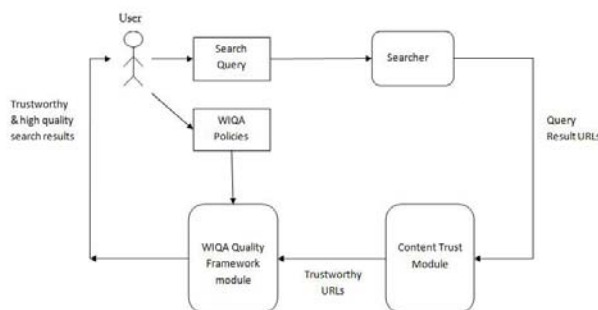


Fig. 1 Trustworthy and High-Quality Information Retrieval System for Web Search Engines

The resultant URLs from the search engine are given as input to the Content Trust Module. The architecture of the Content Trust Module is shown in Fig.2. This Module calculates the website trustworthiness and fact confidence for each of the URLs using the Algorithm for Content Trust Module. The URLs are then filtered based on the calculated trustworthiness. The filtered URLs are given to the WIQA Quality Module which sorts the URLs based on 3 factors – Content, Context and Rating [2]. The Trustworthy and High-Quality Information thus obtained is displayed to the user.

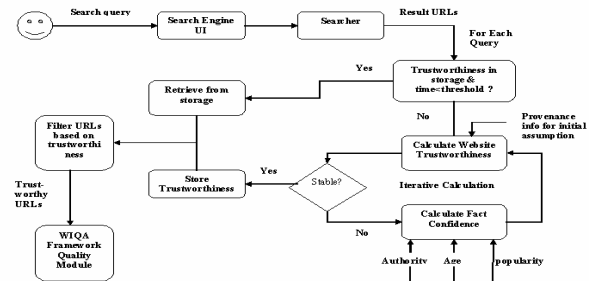


Fig. 2 Content Trust Module

4.1 Architecture of Content Trust Module

The search query given by the user is given to the search engine UI. The searcher gives the resultant URLs. For each URL in the result and the trustworthiness given by $\omega(t)$ is stored and the time of storage is less than a threshold value, then the value of $\omega(t)$ is retrieved from storage. Else, $\omega(t)$ is calculated in an iterative way by assuming initial trustworthiness of the website from the provenance information. From this initial value the fact confidence is calculated based on the parameters Authority, Related Resources, Popularity and Age. From this fact confidence, the website trustworthiness is calculated again.

This process continues in an iterative way till $\omega(t)$ becomes stable. (i.e., The change in $\omega(t)$ compared to the previously calculated $\omega(t)$ is minimum). When $\omega(t)$ becomes stable, it is stored. URLs are filtered based on the value of $\omega(t)$. The filtered URLs are given to the Quality Module.

4.1.1 Calculation of Content Trust parameters

The Authority parameter is calculated by analyzing the URL. Different weights are assigned depending on the domain names. The Age parameter is calculated using the metadata like Last-Modified date. A comparison is done with the current date before assigning the value. The Popularity parameter is calculated using the number of In links, which refer to the number of times a particular website is referenced from other trustworthy websites. The Related

Links parameter is used by adding an appropriate weight to each URL's trustworthiness that is listed out in a Highly-Trustworthy website. These 4 parameters are used to calculate the website trustworthiness.

4.2 Architecture of Quality Module

The Fig.3. Shows how the Quality is achieved using policies selected by the user. Three quality indicators are chosen in the WIQA Policy Framework. The three quality indicators chosen are information content, contextual information and ratings of the website. Various quality dimensions like Accuracy, Timeliness, Relevancy, Objectivity, Believability etc [2] are measured for each URL. The dimensions which are associated with each quality indicator, depends upon the policy selected by the user.

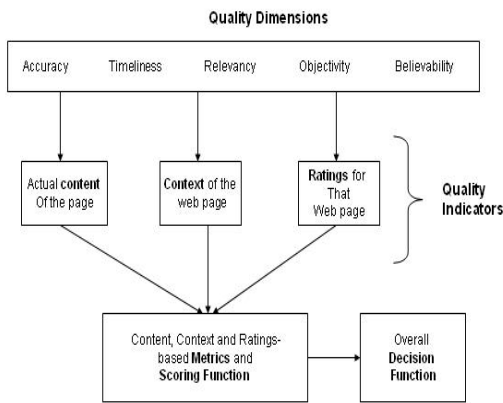
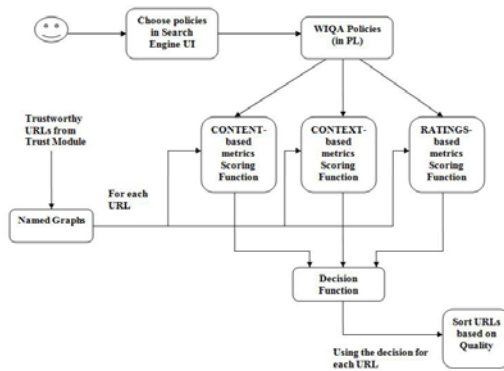


Fig. 3 Achieving Quality

The overall architecture of the Quality Module is shown in Fig.4. The output of the Content Trust module is the input for the Quality module. Trustworthy URLs from the Content Trust module is ranked based on the user selected quality policies.



WIQA – web information quality assessment
 PL – policy language

Fig. 4 WIQA Framework Quality Module

The user chooses the WIQA policies from the search engine UI. The WIQA policies are written in PL language. The user-selected policies specify the type of task at hand of the user. This is used in the calculation of scoring and decision function.

Information quality assessment metrics can be classified into three categories according to the type of information that is used as quality indicator: (1) information content itself; (2) information about the context in which information was claimed; (3) ratings about information itself or the information provider, as seen in Fig.3.

Based on the three quality indicators chosen by the WIQA Framework, three quality assessment metrics are classified: 1) Content based metric 2) Context based metric 3) Ratings based metric.

Context based metrics are assessed based on the provenance information taken from the metadata. Content based metrics are assessed using the information content itself. Ratings based metrics are assessed by using the rating information taken from the linked RDF data sets for all the websites.

Each of these assessment metrics are used to assess the quality dimensions that are relevant for the task at hand. Based on this, each assessment metric specifies a scoring function to calculate an assessment score. Then a decision function weights assessment scores depending on the relevance of the different assessment metric for the task at hand. The URLs are retrieved from the named graph [7] to be used by the scoring function to calculate assessment scores. Then the URLs are ranked based on the decision function.

5. Algorithm for Content Trust Module

The following Content Trust Algorithm calculates the Website Trustworthiness ($\omega(t)$) and Fact Confidence($f(\delta)$) in an iterative fashion where δ represents an URL.

I/P: Set of URLs
 O/P: Trustworthy set of URLs

```

for(each url[i]) /* i – an integer from 1 to n (no of URLs) */
{
    /*Initial Website Trustworthiness  $\omega(t)$ */

    if(url[i] in <url,trust,time,flag> && flag==0 &&
time<threshold)
    {
         $\omega(t_i)$ =trust in <url,trust>;
        goto sort;
    }

    else if(url[i] in <url,trust,time,flag> && flag==1)
    
```

```

    {
        prov=calculate initial  $\omega(t_i)$ ; /*Retrieving provenance info*/
         $\omega(t_i)$ =trust+prov; /*calculating initial assumption for  $\omega(t_i)$ */
    }
    else
    {
        prov=calculate initial  $\omega(t_i)$ ; /*Retrieving provenance info*/
         $\omega(t_i)$ =prov; /*calculating initial assumption for wt*/
    }

    /*Calculate Fact Confidence*/
     $f_1(\delta)$ =retrieveauth(url[i]); /*Retrieve authority info from
    domain names*/
     $f_2(\delta)$ =retrieveage(url[i]); /*Retrieve age info from last-
    modified date*/
     $f_3(\delta)$ =retrievepop(url[i]); /*Retrieve popularity from websites*/
    rel=retrieverel(url[i]); /*Retrieve related websites from
    outlinks*/

    do /*Iterative computation*/
    {
        temp=  $\omega(t_i)$ ; /* calculation of fact confidence*/

         $s(\delta) = \sum_{x=1,2,3} f_x(\delta)$ ; /*Fact score*/

        if( $s(\delta)$ <1) /* fact confidence */
             $f(\delta) = \log [ -\ln (s(\delta)) + \omega(t_i)$ ];
        else
             $f(\delta) = \log [ \ln (s(\delta)) + \omega(t_i)$ ];

         $\omega(t_i) = e^{f(\delta)} + e^{f(\delta)/2}$ ; /* calculation of website
        trustworthiness */

        diff= |temp-  $\omega(t_i)$ ];
    } while (diff>0.05);

    trust[i] =  $\omega(t_i)$ ;

    create entry and store (url, $\omega(t_i)$ ,time,0) in <url,trust,time,flag>;

    for(each url in rel)
    {
        if(url in <url,trust,time,flag>)
            break;

        else
        {
            create entry <url,trust,time,flag>;
            trust=  $\omega(t_i)$ /5;
            flag=1;
        }
    }
}
Sort:
sort URLs based on trust[i];
}
    
```

5.1 Formulation:

Fact Score (s(δ)) :

$$s(\delta) = \sum_{x=1,2,3} f_x(\delta)$$

Fact confidence (f(δ)) :

$$f(\delta) = \log [\ln (s(\delta)) + \omega(t_i)]$$

Website Trustworthiness ($\omega(t_i)$) :

$$\omega(t_i) = e^{f(\delta)} + e^{f(\delta)/2}$$

$f_x(\delta)$ – Weight of the parameters Age, Authority and Popularity

6. Result analysis

The preliminary results of the proposed Trustworthy and High-Quality Information Retrieval System for Web Search Engines is shown in Fig.5 and Fig.6

This work uses the open source search engine NUTCH and it is modified to incorporate the Content Trust Module and Quality Module.

Fig.5 shows the unmodified NUTCH search results for the query “Study in US”. Fig.6 shows the modified NUTCH search results for the same query.

The search results differ in a way that the modified Nutch provides more authoritative websites like .gov and .edu, more recently modified websites, websites from a trusted source and websites with high popularity in the top search results.

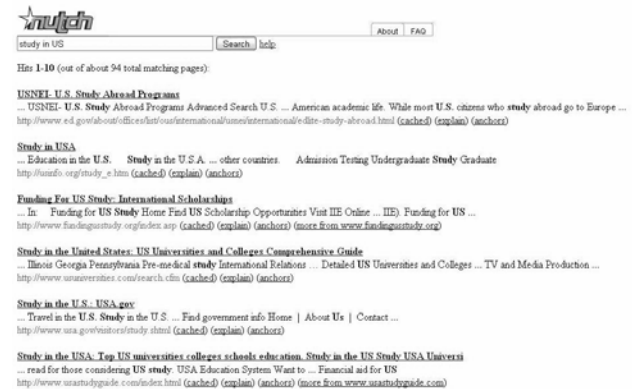


Fig.5. Unmodified NUTCH search results for the query “Study in US”



Fig.6. Modified NUTCH search results for the query “Study in US”

7. Conclusion and Future Work

The web search results from the search engines which implement the Trustworthy and High-Quality Information Retrieval System contain more accurate websites with trustworthy information. The search results provide the most truthful information. The search results are also ranked based on user-selected quality criteria. Performance of retrieving trustworthy data is also improved.

There are about 16 factors which affect the Content Trust of websites[5]. The future work will be in analyzing the remaining parameters and checking their feasibility in providing trustworthiness.

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A New Computational Schema for Euphonic Conjunctions in Sanskrit Processing

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Abstract

Automated language processing is central to the drive to enable facilitated referencing of increasingly available Sanskrit E-texts. The first step towards processing Sanskrit text involves the handling of Sanskrit compound words that are an integral part of Sanskrit texts. This firstly necessitates the processing of euphonic conjunctions or *sandhi*-s, which are points in words or between words, at which adjacent letters coalesce and transform.

The ancient Sanskrit grammarian Pāṇini's codification of the Sanskrit grammar is the accepted authority in the subject. His famed *sūtra*-s or aphorisms, numbering approximately four thousand, tersely, precisely and comprehensively codify the rules of the grammar, including all the rules pertaining to *sandhi*-s.

This work presents a fresh new approach to processing *sandhi*-s in terms of a computational schema. This new computational model is based on Pāṇini's complex codification of the rules of grammar. The model has simple beginnings and is yet powerful, comprehensive and computationally lean.

Keywords: *Sanskrit, euphonic conjunction, sandhi, linguistics, Panini, aphorism, sutra.*

1. Introduction

The recognition of Sanskrit as a highly phonetic language as also one with an extensively codified grammar [1], is widespread. The very name *Saṃskṛt* (Sanskrit) means "language brought to formal perfection". That the Backus-Naur Form used in the specification of formal languages, has now come to be popularly known as the Pāṇini-Backus Form [8, 9], bears ample testimony to this fact.

Sanskrit E-texts are being increasingly made available for reference in repositories such as the Göttingen Register of Electronic Texts in Indian Languages (GRETIL) [11]. Now the essential first step towards language processing of such Sanskrit E-texts is to develop efficient algorithms and tools to handle segmentation in Sanskrit compound words that are an integral part of Sanskrit texts. This firstly

necessitates the processing of *sandhi*-s or euphonic conjunctions.

1.1 Unicode Representation

The Unicode (UTF-8) standard is what has been adopted universally for the purpose of encoding Indian language texts into digital format. The Unicode Consortium has assigned the Unicode hexadecimal range 0900 - 097F for Sanskrit characters.

All characters including the diacritical characters used to represent Sanskrit letters in E-texts are found dispersed across the Basic Latin (0000-007F), Latin-1 Supplement (0080-00FF), Latin Extended-A (0100-017F) and Latin Extended Additional (1E00 - 1EFF) Unicode ranges.

The Latin character set has been employed in this work to represent Sanskrit letters as E-text. Moreover in this paper, any Sanskrit text except the names of people is given in italics. As such, variables such as x, y and z are not italicized as per the norm.

1.2 The Basis of the Work

Pāṇini, the sage and scholar dated by historians in the fourth century BC or earlier, codified the rules of the Sanskrit language based on both the extant vast literature as well as the language in prevalent use at the time. His magnum opus, the *Aṣṭādhyāyī*, which literally means 'work in eight chapters', is regarded by all scholars as the ultimate authority on Sanskrit grammar. In four parts each, these eight chapters comprise nearly four thousand *sūtra*-s or aphorisms, terse statements in Sanskrit. This grammar-codification of Pāṇini is perhaps unparalleled, for it is terse and yet comprehensive, complex yet precise. Intensive study, taking recourse to authoritative commentaries authored by adroit grammarians, is required to get a grasp of the work.

Many commentaries on the *Aṣṭādhyāyī*, such as Sage Patañjali's *Mahābhāṣya* are available and held as authentic



and comprehensive. One such authoritative commentary with a neat, topic-wise classification of Pāṇini's aphorisms, is the *Siddhānta-kaumudī* [2] written in the seventeenth century by the Sanskrit grammarian, Bhaṭṭoji Dīkṣita. The most important of these aphorisms were later extracted and compiled into the *Laghu-siddhānta-kaumudī* [10] by the scholar Varadarāja.

It is accepted among Sanskrit scholars that any exploratory work on Sanskrit grammar must necessarily have the aphorisms of Pāṇini as its basis, optionally taking recourse to any of the authoritative commentaries. This work on euphonic conjunctions is also based directly on Pāṇini's aphorisms, and not on secondary or tertiary sources of information. The *Siddhānta-kaumudī* of Bhaṭṭoji Dīkṣita, famed and accepted amongst scholars as an unabridged, comprehensive compendium of the entire *Aṣṭādhyāyī*, has been studied in the original Sanskrit, and the euphonic conjunctions dealt with in it form the basis of this work. The *Laghu-siddhānta-kaumudī* was also initially consulted for insights.

1.3 The *Māheśvara* aphorisms - the backbone of Pāṇini's code

The *Māheśvara* aphorisms, said to have come from the beats of a special drum called '*ḍamaru*' (hourglass drum) held in the hand of Lord Maheśvara (a form of God in the Hindu pantheon), are a set of aphorisms containing the letters of the Sanskrit alphabet in a certain sequence. These aphorisms form the basis of Pāṇini's composition of his grammar aphorisms. The *Māheśvara* aphorisms are fourteen in number and are listed below:

1. *a-i-u-ṅ*
2. *ṛ-l-k*
3. *e-o-ṅ*
4. *ai-au-c*
5. *ha-ya-va-ra-ṭ*
6. *la-ṅ*
7. *ṅa-ma-ṅa-ṅa-na-m*
8. *jha-bha-ṅ*
9. *gha-dha-dha-ṣ*
10. *ja-ba-ga-da-da-ś*
11. *kha-pha-cha-ṭha-ṭha-ca-ṭa-ta-v*
12. *ka-pa-y*
13. *śa-ṣa-sa-r*
14. *ha-l*

The last letter in each of the above aphorisms is only a place-holder and is not counted as an actual letter of the aphorism. The first four aphorisms list the short forms of all the vowels, while the rest list the consonants. It must be noted that the letter 'a' added to each of the consonants is only to facilitate pronunciation and is not part of the consonant proper.

2. The Problem

Sandhi-s in Sanskrit are points in words or between words, at which adjacent letters coalesce and transform. This is a common feature of Indian languages and is particularly elaborately dealt with and used in Sanskrit. The

transformations that apply are commonly categorized into four:

1. *āgama* – addition of an extra letter or set of letters
2. *ādeśa* – substitution of one or more of the letters
3. *lopa* – dropping of a letter
4. *prakṛtibhāva* – no change

(The last is considered a transformation in the language and has therefore been listed above. However, it may be ignored for practical purposes and is hence not covered in this work.)

There are close to seventy aphorisms of Pāṇini that deal with *sandhi*-s. These aphorisms lay out the rules for the above transformations, giving the conditions under which certain letters combine with certain others to give particular results.

The challenge is to develop a computational algorithm to handle the entire range of *sandhi*-s. Such a computational algorithm would be useful to generate various word forms of a given Sanskrit word through the application of *sandhi* rules. Though this task is not difficult for a scholar of Sanskrit with a thorough knowledge of the Pāṇinian system, it is certainly a computationally non-trivial task, given the complexity and number of rules.

Existing methods of *sandhi* processing, be they methods to form compound words or even to try to split them, seem to be based on a derived understanding of the functioning of euphonic conjunctions, and usually go the finite automata-HMM-artificial intelligence way [3-7, 12]. However, the present work directly codifies Pāṇini's rules as is, recognizing that Pāṇini's codification of the grammar is based on the *Māheśvara* aphorisms that in turn lay out the letters of the alphabet in a non-trivial order. This work presents one novel method of directly representing Pāṇini's *sandhi* rules. It presents, on this basis, a mathematical formulation of a new approach to solving the non-trivial problem of handling euphonic conjunctions.

3. The Approach

To take advantage of the ordering of letters of the alphabet given in 2.3 above, we assign values to each letter in the Sanskrit alphabet, sticking to the order in the *Māheśvara* aphorisms rather than to the commonly adopted ordering of the letters. Thus, we have the assignment of values for the letters of the alphabet shown in Table 1.

Table 1 : Values for the letters of the Sanskrit alphabet

Letter	Value	Letter	Value	Letter	Value
<i>a</i>	1	<i>l</i>	18	<i>ph</i>	35
<i>ā</i>	2	<i>ṅ</i>	19	<i>ch</i>	36
<i>i</i>	3	<i>m</i>	20	<i>ṭh</i>	37
<i>ī</i>	4	<i>ṇ</i>	21	<i>th</i>	38
<i>u</i>	5	<i>n</i>	22	<i>c</i>	39
<i>ū</i>	6	<i>ṅ</i>	23	<i>ṭ</i>	40
<i>ṛ</i>	7	<i>jh</i>	24	<i>t</i>	41
<i>ṝ</i>	8	<i>bh</i>	25	<i>k</i>	42
<i>l</i>	9	<i>gh</i>	26	<i>p</i>	43
<i>e</i>	10	<i>dh</i>	27	<i>ś</i>	44
<i>o</i>	11	<i>dh</i>	28	<i>ṣ</i>	45



<i>ai</i>	12	<i>j</i>	29	<i>s</i>	46
<i>au</i>	13	<i>b</i>	30	<i>h</i>	47
<i>h</i>	14	<i>g</i>	31	<i>m̄</i>	48
<i>y</i>	15	<i>d̄</i>	32	<i>ḥ</i>	49
<i>v</i>	16	<i>d</i>	33	'	50
<i>r</i>	17	<i>kh</i>	34	<i>ru</i>	51

Further, the letters are clubbed into various types as given below:

1. vowels: 1 – 13
2. consonants: 14 – 47
3. semi-vowels: 15 – 18
4. mutes: 19 – 47
5. nasals: 19 – 23
6. non-nasal mutes: 24 - 47
7. soft consonants: 24 – 33
8. hard consonants: 34 - 46
9. column 1: 39 – 43
10. column 2: 34 – 38
11. column 3: 29 – 33
12. column 4: 24 – 28
13. sibilants: 44 – 46
14. aspirate: 14 and 47
15. *anusvāra*: 48
16. *visarga*: 49
17. *avagraha*: 50 (replacement for the first vowel)
18. *ru*: 51 (denotes the letter *r* but is handled differently)
19. gutturals: 42, 34, 31, 26, 21
20. palatals: 39, 36, 29, 24, 19
21. cerebrals: 40, 37, 32, 27, 22
22. dentals: 41, 38, 33, 28, 23
23. labials: 43, 35, 30, 25, 20

A **rule** is the name we use for letter-level conjunctions such as the following of the *savarnadīrgha* type: $a + \bar{a} = \bar{a}$ where the symbol '+' denotes adjacency and the term on the right of the '=' symbol is the resultant term that has to be either substituted for or added to ones on the left. (In the case of this particular *sandhi*, the term on the right is the single substitute for both terms on the left.) Substituting values of letters from Table 1, this would translate into $1+2 = 2$.

Each *sandhi* may have more than one governing aphorism that specifies its functioning. Each such aphorism for every *sandhi* type in turn expands into a series of 'rules' as defined above. In this work, each and every rule for each aphorism under each of the major twenty three *sandhi* types were listed. Further, an aphorism would specify if an addition, deletion or substitution would have to be made. In accordance with this, a further cataloguing of aphorisms into five categories was done.

If we denote a *sandhi* rule as $x + y = z$ where variables *x* and *y* denote the values of single letters joining together to yield a resultant *z*, then we have the following categorizations depending on both the characteristics of *z* and on what we actually do with it:

- C₁: replace *x* and *y* with single-letter or multi-letter *z*
- C₂: replace *x* with single-letter or multi-letter *z*
- C₃: replace *y* with single-letter *z*
- C₄: add single-letter *z*
- C₅: drop *x*

Table 2 gives the summary of the numbers involved in this scenario. It must be noted that in practice, some aphorisms have to be combined or handled in two different ways to yield sets of rules, and hence what may seem to be a discrepancy in the number of aphorisms shown in the table and the number of rows shown for the rules of that aphorism, is no real discrepancy at all.

As can be seen, there are close to 2500 individual rules involved, even with considering only the major *sandhi*-s. Tabulation of these rules in terms of *x*, *y* and *z* for the categories and then tabulation of the corresponding values as per Table 1 were done.

Table 2: Summary of the number of Sanskrit *sandhi* aphorisms and rules

#	Sandhi Type	No. of sūtra-s	Categories					No. of Rules
			C ₁	C ₂	C ₃	C ₄	C ₅	
1	<i>yañādeśa</i>	1		74				74
2	<i>ayāyāvāvādeśa</i>	4		50				50
				2				2
				3				3
3	<i>guṇa</i>	2	8					8
			18					18
4	<i>vṛddhi</i>	3	8					8
			18					18
			10					10
5	<i>pararūpa</i>	1	10					10
6	<i>savarnadīrgha</i>	1	15					15
7	<i>pūrvārūpa</i>	1	2					2
8	<i>avañādeśa</i>	1		13				13
9	<i>tugāgama</i>	4				13		13
						1		1
10	<i>jaṣṭva</i>	2		23				23
				240				240
11	<i>satva</i>	2		5				5
				230				230
				138				138
12	<i>anusvāra</i>	5		34				34
				24				24
				1				1
				3				3
13	<i>dhuḍāgama</i>	2				2		2
14	<i>ñamudāgama</i>	1				195		195
15	<i>ścutva</i>	2		36				36
					31			31
16	<i>ṣṭutva</i>	3		31				31
					6			6
17	<i>anunāsikā</i>	1		160				160
18	<i>cartva</i>	1		312				312
19	<i>parasavarṇa</i>	3		29				29
				5				5
20	<i>pūrvasavarṇa</i>	1			20			20
21	<i>chatva</i>	1			340			340
22	<i>visarga</i>	2		13				13
				13				13
23	<i>svādi</i>	5					66	66
							13	13
							132	132
							33	33
							33	33
TOTAL		49	89	1439	397	211	277	2413

Careful observations based on a thorough understanding of the domain and classification of the input conditions, yielded the equations presented in this work.

We define the general binary operators $\oplus_1, \oplus_2, \oplus_3, \oplus_4$ and \oplus_5 for the categories C_1, C_2, C_3, C_4 and C_5 respectively, as follows:

$$C_1: \oplus_1(x, y) = z = z_1$$

$$C_2: \oplus_2(x, y) = z = z_2y$$

$$C_3: \oplus_3(x, y) = z = xz_3$$

$$C_4: \oplus_4(x, y) = z = xz_4y$$

$$C_5: \oplus_5(x, y) = z = y$$

where each of z_1, z_2, z_3, z_4 is to be calculated. Now we introduce the second and third subscripts for the above general operators as follows: the general operator $\oplus_{i,j}(x, y)$ is derived from \oplus_i and signifies the operator applying to aphorism number j of Category C_i ; the specialized operator $\oplus_{i,j,k}(x, y)$ is derived from the operator $\oplus_{i,j}$ and appertains to the k^{th} equation for the j^{th} aphorism of Category C_i . These two extra subscripts are necessitated by the facts that a category encompasses many aphorisms and one aphorism may itself be governed by more than one equation.

4. Results and Discussion

The main *sandhi* aphorisms, their brief description (Rule), the corresponding general operator and the final, specialized equations along with the domain of operation are given below in a category-wise listing. Special notations followed are:

- The equations and conditions given as operators with three subscripts are the ones that are implementable. The 'general operator' specified for each aphorism typifies the aphorism's meaning and all the conditions it becomes operative under, and provides a generalization from which the final equations are specialized. A specialized operator would thus override the 'general operator' with its own specialized conditions.
- The variable X denotes the sequence of letters culminating in x ; the variable Y denotes the sequence of letters starting with y . These are used to depict special conditions that pertain to the entire word involved in the *sandhi*.
- Variables u and w represent the value of the letter occurring just before x and just after y respectively.
- [] are used to club domain conditions simply in order to depict the 'or' condition more clearly.

4.1 C_1 Sandhi-s

guṇa sandhi

1. *ādguṇah* || 6.1.87 ||

Rule: a or \bar{a} followed by i, u (short and long) \rightarrow *guṇa* letter (e, o) corresponding to second letter replaces both.

General operator: $\oplus_{1,1}(x, y) = z = z_1$ when $x \in \{1, 2\}, y \in \{3, 4, 5, 6\}$

$$\oplus_{1,1,1}(x, y) : z_1 = 10 \text{ when } y \in \{3, 4\}$$

$$\oplus_{1,1,2}(x, y) : z_1 = 11 \text{ when } y \in \{5, 6\}$$

2. *uraṇ raparah* || 1.1.51 ||

Rule: a or \bar{a} followed by r (short and long), $l \rightarrow$ *guṇa* letter (ar, al) corresponding to the second letter replaces both.

General operator: $\oplus_{1,2}(x, y) = z = z_1 = z_{11}z_{12}$ when $x \in \{1, 2\}, y \in \{7, 8, 9\}$

$$\oplus_{1,2,1}(x, y) : z_{11} = 1, z_{12} = 17 \text{ when } y \in \{7, 8\}$$

$$\oplus_{1,2,2}(x, y) : z_{11} = 1, z_{12} = 18 \text{ when } y \in \{9\}$$

vṛddhi sandhi

3. *vṛddhireci* || 6.1.88 ||

Rule: a or \bar{a} followed by $e, o, ai, au \rightarrow$ *vṛddhi* letter (ai, au) corresponding to second letter replaces both.

General operator: $\oplus_{1,3}(x, y) = z = z_1$ when $x \in \{1, 2\}, y \in \{10, 11, 12, 13\}$

$$\oplus_{1,3,1}(x, y) : z_1 = y + 2 \text{ when } y \in \{10, 11\}$$

$$\oplus_{1,3,1}(x, y) : z_1 = y \text{ when } y \in \{12, 13\}$$

4. *etyedhatyūṭhsu* || 6.1.89 ||

Rule: In all the following rules, *vṛddhi* letter ($ai, au, \bar{a}r, \bar{a}l$) corresponding to the beginning of second word, replaces both.

- a or \bar{a} followed by the prepositions *eti, edhati* \rightarrow *ai* replaces both
- preposition *pra* followed by *eṣah, eṣya* \rightarrow *ai* replaces both
- word *sva* followed by \bar{r} \rightarrow *ai* replaces both
- a or \bar{a} followed by the preposition *ūh* \rightarrow *au* replaces both
- word *akṣa* followed by word *ūhini* \rightarrow *au* replaces both
- preposition *pra* followed by *ūh, ūḍh* \rightarrow *au* replaces both

General operator: $\oplus_{1,4}(x, y) = z = z_1$ when $x \in \{1, 2\}$

$$\oplus_{1,4,1}(x, y) : z_1 = 12 \text{ when } [y = 10, Y \in \{10+41+3, 10+28+1+41+3\}] \text{ or } [x = 1, y = 10, X \in \{43+17+1\}] \text{ or } [x = 1, y = 4, X \in \{46+16+1\}, Y \in \{4+17\}]$$

$$\oplus_{1,4,2}(x, y) : z_1 = 13 \text{ when } [y = 6, Y \in \{6+14\}] \text{ or } [x = 1, y = 6, X \in \{1+42+45+1\}, Y \in \{6+14+3+23+3\}] \text{ or } [x = 1, y = 6, X \in \{43+17+1\}, Y \in \{4+17, 4+27\}]$$

5. *etyedhatyūṭhsu* || 6.1.89 ||

Rule: In all the following rules, *vṛddhi* letter ($ai, au, \bar{a}r, \bar{a}l$) corresponding to the beginning of second word, replaces both.

- a followed by word *ṛta* \rightarrow $\bar{a}r$ replaces both
- preposition/words *pra, vatsara, kambala, vasana, daśa, ṛṇa* followed by the word *ṛṇa* \rightarrow $\bar{a}r$ replaces both

General operator: $\oplus_{1,5}(x, y) = z = z_1 = z_{11}z_{12}$ when $x = 1$

$$\oplus_{1,5,1}(x, y) : z_{11} = 2, z_{12} = y + 10 \text{ when } [y = 7, Y \in \{7+41+1\}] \text{ or } [X \in \{43+17+1, 16+1+41+46+1+17+1, 42+1+20+30+1+18+1, 16+1+46+1+23+1, 33+1+44+1, 7+22+1\}, Y \in \{7+22+1\}]$$

6. *upasargādṛti dhātau* || 6.1.91 ||

Rule: a or \bar{a} at the end of prepositions followed by $r \rightarrow$ *vṛddhi* letter $\bar{a}r$ replaces both. (The prepositions that qualify are: *pra, parā, apa, ava, upa*)

General operator: $\oplus_{1,6}(x, y) = z = z_1 = z_{11}z_{12}$ when $x \in \{1, 2\}, y = 7$

$\oplus_{1,6,1}(x, y) : z_{11} = 2, z_{12} = y + 10$ when $X \in \{43+17+1, 43+1+17+2, 1+43+1, 1+16+1, 5+43+1\}$

pararūpa sandhi

7. *eṇi pararūpam* || 6.1.94 ||

Rule: *a* or *ā* at the end of a preposition followed by *e* or *o* (of a verbal root) \rightarrow second letter (*e* or *o*) replaces both.

General operator: $\oplus_{1,7}(x, y) = z = z_1 = y$ when $x \in \{1, 2\}, y \in \{10, 11\}$

$\oplus_{1,7,1}(x, y) : z_1 = y$ when $x \in \{1, 2\}, y \in \{10, 11\}, X \in \{43+17+1, 43+1+17+2, 1+43+1, 1+16+1, 5+43+1\}$

savarṇadīrgha sandhi

8. *akah savarṇe dīrghah* || 6.1.101 ||

Rule: *a, i, u, r, l* (short or long) followed by similar *a, i, u, r, l* (short or long) \rightarrow corresponding long letter replaces both.

General operator: $\oplus_{1,8}(x, y) = z = z_1 = y$ when $1 \leq x \leq 9, 1 \leq y \leq 9$

All operators $\oplus_{1,8,i}$ are commutative.

$\oplus_{1,8,1}(x, y) : z_1 = y$ when $[x \in \{1, 3, 5\}, y = x+1]$ or $[x \in \{2, 4, 6\}, y = x]$

$\oplus_{1,8,2}(x, y) : z_1 = y + 1$ when $x \in \{1, 3, 5\}, y = x$

$\oplus_{1,8,3}(x, y) : z_1 = 8$ when $x, y \in \{7, 8, 9\}$

pūrvarūpa sandhi

9. *eṇah padāntādāti* || 6.1.109 ||

Rule: *e* or *o* followed by *a* \rightarrow first letter replaces both.

General operator: $\oplus_{1,9}(x, y) = z = z_1 = x$ when $x \in \{10, 11\}, y = 1$

$\oplus_{1,9,1}(x, y) : z_1 = x$ when $x \in \{10, 11\}, y = 1$

4.2 C₂ Sandhi-s

yañādeśa sandhi

1. *iko yanaci* || 6.1.77 ||

Rule: *i, u, r, l* (short and long) followed by dissimilar vowel $\rightarrow y, v, r, l$ respectively replace first letter.

General operator: $\oplus_{2,1}(x, y) = z = z_2y$ when $3 \leq x \leq 9, y \leq 13$

$\oplus_{2,1,1}(x, y) : z_2 = 15$ when $x \in \{3, 4\}, y \in \{3, 4\}$

$\oplus_{2,1,2}(x, y) : z_2 = 16$ when $x \in \{5, 6\}, y \in \{5, 6\}$

$\oplus_{2,1,3}(x, y) : z_2 = 17$ when $x \in \{7, 8\}, y \in \{7, 8, 9\}$

$\oplus_{2,1,4}(x, y) : z_2 = 18$ when $x \in \{9\}, y \in \{7, 8, 9\}$

ayāya-avāva-ādeśa sandhi

2. *ecoyavāyāvah* || 6.1.78 ||

Rule: *e, o* followed by *āc* $\rightarrow ay, av$ replace the first respectively;

ai, au followed by *ac* $\rightarrow āy, āv$ replace the first respectively.

General operator: $\oplus_{2,2}(x, y) = z = z_2y = z_{21}z_{22}y$ when $10 \leq x \leq 13, y \leq 13$

$\oplus_{2,2,1}(x, y) : z_{21} = 1, z_{22} = x + 5$ when $x \in \{10, 11\}, y \neq 1$

$\oplus_{2,2,2}(x, y) : z_{21} = 2, z_{22} = x + 3$ when $x \in \{12, 13\}$

3. *vānto yi pratyaye* || 6.1.79 ||

Rule: *o, au* followed by *y* $\rightarrow av, āv$ replace the first respectively.

General operator: $\oplus_{2,3}(x, y) = z = z_2y = z_{21}z_{22}y$ when $x \in \{11, 13\}, y = 15$

$\oplus_{2,3,1}(x, y) : z_{21} = 1, z_{22} = x + 5$ when $x = 11$

$\oplus_{2,3,1}(x, y) : z_{21} = 2, z_{22} = x + 3$ when $x = 13$

4. *kṣayyajayyau śakyārthe* || 6.1.81 ||

kṛayyastadarthe || 6.1.82 ||

Rule: *e* which is the end of words *kṣe, je, kre* followed by *y* $\rightarrow ay$ replaces the first.

General operator: $\oplus_{2,4}(x, y) = z = z_2y = z_{21}z_{22}y$ when $x = 10, y = 15, X \in \{42+45+10, 29+10\}$

$\oplus_{2,4,1}(x, y) : z_{21} = 1, z_{22} = x + 5$

avañādeśa sandhi

5. *avañ sphotāyanasya* || 6.1.123 ||

Rule: *o* which is the end of word *go* followed by a vowel \rightarrow 'ava' replaces the first.

General operator: $\oplus_{2,5}(x, y) = z = z_2y = z_{21}z_{22}z_{23}y$ when $x = 11, y \leq 13, X = 31+11$

$\oplus_{2,5,1}(x, y) : z_{21} = 1, z_{22} = 16, z_{23} = 1$

jaṣṭva sandhi

6. *jhalām jaśo 'nte* || 8.2.39 ||

Rule: non-nasal mutes, sibilants, aspirate at the end of a word \rightarrow first letter replaced by corresponding column 3 letter.

General operator: $\oplus_{2,6}(x, y) = z = z_2y$ when $24 \leq x \leq 47, y = 0$

$\oplus_{2,6,1}(x, y) : z_2 = x + 5$ when $x \in \{24, 25, 26, 27, 28\}$

$\oplus_{2,6,2}(x, y) : z_2 = x$ when $x \in \{29, 30, 31, 32, 33, 44, 45, 47\}$

$\oplus_{2,6,3}(x, y) : z_2 = x - 3$ when $x = 34$

$\oplus_{2,6,4}(x, y) : z_2 = x - 5$ when $x \in \{35, 37, 38\}$

$\oplus_{2,6,5}(x, y) : z_2 = x - 7$ when $x = 36$

$\oplus_{2,6,6}(x, y) : z_2 = x - 8$ when $x \in \{40, 41\}$

$\oplus_{2,6,7}(x, y) : z_2 = x - 11$ when $x = 42$

$\oplus_{2,6,8}(x, y) : z_2 = x - 13$ when $x = 43$

$\oplus_{2,6,9}(x, y) : z_2 = x - 10$ when $x = 39$

satva sandhi

7. *samaḥ suṭi* || 8.3.5 ||

Rule 1: word *sam* followed by affixes *ḱr, kṛ, kar, kār, kur* $\rightarrow m$ of *sam* replaced with the combination *ms*.

General operator: $\oplus_{2,7}(x, y) = z = z_2y = z_{21}z_{22}y$ when $x = 20, y = 42, X \in \{46+1+20\}, Y \in \{42+7, 42+8, 42+1+17, 42+2+17, 42+5+17\}$

$\oplus_{2,7,1}(x, y) : z_{21} = 48, z_{22} = 46$

8. *pumaḥ khayyampare* || 8.3.6 ||

Rule: word *pum* followed by column 1, column 2 which is in turn followed by a vowel, aspirate, semi-vowel or nasal \rightarrow ending *m* replaced with the combination *ms*.

General operator: $\oplus_{2,8}(x, y) = z = z_2y = z_{21}z_{22}y$ when $x = 20, 34 \leq y \leq 43, 1 \leq w \leq 23$

$\oplus_{2,8,1}(x, y) : z_{21} = 48, z_{22} = 46$

9. *naśchavyaprasān* || 8.3.7 ||

Rule: final *n* of a word except for the word *prasān*, followed by *ch, ih, th, c, t, t* which is in turn followed by a vowel, aspirate, semi-vowel or nasal \rightarrow ending *n* replaced with the combination *ms*.

General operator: $\oplus_{2,9}(x, y) = z = z_2y = z_{21}z_{22}y$ when $x = 23, 36 \leq y \leq 41, 1 \leq w \leq 23, X \in \{43+17+1+44+2+23\}$

$\oplus_{2,9,1}(x, y) : z_{21} = 48, z_{22} = 46$

visarga sandhi

10. *kharavasānāyorvisarjanīyaḥ* || 8.3.15 ||

Rule: *r* followed by hard consonant \rightarrow *r* replaced with *visarga*.

General operator: $\oplus_{2,10}(x, y) = z = z_2y$ when $x = 17, 34 \leq y \leq 46$

$\oplus_{2,10,1}(x, y) : z_2 = 49$

anusvāra sandhi

11. *mo'nusvārah* || 8.3.23 ||

mo rāji samah kvau || 8.3.25 ||

Rule: *m* followed by any consonant \rightarrow *m* letter replaced by *m̄* (*anusvāra*) (except in the case of the word *sam* being followed by the word *rāt*)

General operator: $\oplus_{2,11}(x, y) = z = z_2y$ when $x = 20, 14 \leq y \leq 47, X \in \{46+1+20\}, Y \in \{17+2+40\}$

$\oplus_{2,11,1}(x, y) : z_2 = 48$

12. *naścāpadāntasya jhali* || 8.3.24 ||

Rule: *n* followed by a non-nasal mute, sibilant or aspirate (not at the end of a *pada*) \rightarrow *n* replaced by *m̄* (*anusvāra*).

General operator: $\oplus_{2,12}(x, y) = z = z_2y$ when $x = 23, 24 \leq y \leq 47$

$\oplus_{2,12,1}(x, y) : z_2 = 48$

13. *he mapare vā* || 8.3.26 ||

Rule: *m* followed by *h* which is in turn followed by *y, l, or v* \rightarrow the first *m* replaced by *nasal y, l, v* (i.e. *m̄y, m̄l, m̄v*) respectively.

General operator: $\oplus_{2,13}(x, y) = z = z_2y = z_{21}z_{22}y$ when $x = 20, y = 14, w \in \{15, 16, 18\}$

$\oplus_{2,13,1}(x, y) : z_{21} = 48, z_{22} = w$

14. *napare nah* || 8.3.27 ||

Rule: *m* followed by *h* at the end of a *pada* which is in turn followed by *n* \rightarrow *m* replaced by *n*.

General operator: $\oplus_{2,14}(x, y) = z = z_2y$ when $x = 20, y = 14, w = 23$

$\oplus_{2,14,1}(x, y) : z_2 = w$

visarga sandhi

15. *visarjanīyasya sah* || 8.3.34 ||

Rule: *visarga* followed by hard consonant \rightarrow *visarga* replaced with *s*.

General operator: $\oplus_{2,15}(x, y) = z = z_2y$ when $x = 49,$

$34 \leq y \leq 46, w \in \{44, 45, 46\}$

$\oplus_{2,15,1}(x, y) : z_2 = 46$

ścutva sandhi

16. *stoḥ ścunāḥ ścuḥ* || 8.4.40 ||

Rule: dentals, *s* followed by palatals, *ś* \rightarrow first replaced by its corresponding palatal, *ś* respectively.

General operator: $\oplus_{2,16}(x, y) = z = z_2y$ when $x \in \{41, 38, 33, 28, 23, 46\}, y \in \{39, 36, 29, 24, 19, 44\}$

$\oplus_{2,16,1}(x, y) : z_2 = x - 2$ when $x \in \{41, 38, 46\}$

$\oplus_{2,16,2}(x, y) : z_2 = x - 4$ when $x \in \{33, 28, 23\}$

ṣṭutva sandhi

17. *ṣṭunāḥ ṣṭuḥ* || 8.4.41 ||

toḥ ṣi || 8.4.43 ||

Rule: [dentals, *s* followed by cerebrals] or [*s* followed by *ṣ*] \rightarrow dentals or *s* replaced by cerebrals or *ṣ* respectively.

General operator: $\oplus_{2,17}(x, y) = z = z_2y$ when $x \in \{41, 38, 33, 28, 23, 46\}, y \in \{40, 37, 32, 27, 22, 45\}$

$\oplus_{2,17,1}(x, y) : z_2 = x - 1$ when [$x = 46$] or [$y \neq 45$]

anunāsikā sandhi

18. *yaro'nunāsike'nunāsiko vā* || 8.4.45 ||

Rule: semi-vowels *y, v* and *l* followed by nasal \rightarrow first replaced by its corresponding nasal, *m̄y, m̄v, m̄l* respectively.

General operator: $\oplus_{2,18}(x, y) = z = z_2y = z_{21}z_{22}y$ when $x \in \{15, 16, 18\}, 19 \leq y \leq 23$

$\oplus_{2,18,1}(x, y) : z_{21} = 48, z_{22} = x$

19. *yaro'nunāsike'nunāsiko vā* || 8.4.45 ||

Rule: semi-vowel *r*, mutes, sibilants followed by nasal \rightarrow first replaced by its corresponding nasal.

General operator: $\oplus_{2,19}(x, y) = z = z_2y$ when $17 \leq x \leq 46, x \neq 18, 19 \leq y \leq 23$

$\oplus_{2,19,1}(x, y) : z_2 = x$ when $x \in \{17, 19, 20, 21, 22, 23, 44, 45, 46\}$

$\oplus_{2,19,2}(x, y) : z_2 = x - 5$ when $x \in \{24, 25, 26, 27, 28\}$

$\oplus_{2,19,3}(x, y) : z_2 = x - 10$ when $x \in \{29, 30, 31, 32, 33\}$

$\oplus_{2,19,4}(x, y) : z_2 = x - 13$ when $x = 34$

$\oplus_{2,19,5}(x, y) : z_2 = x - 15$ when $x \in \{35, 37, 38\}$

$\oplus_{2,19,6}(x, y) : z_2 = x - 17$ when $x = 36$

$\oplus_{2,19,7}(x, y) : z_2 = x - 18$ when $x \in \{40, 41\}$

$\oplus_{2,19,8}(x, y) : z_2 = x - 20$ when $x = 39$

$\oplus_{2,19,9}(x, y) : z_2 = x - 21$ when $x = 42$

$\oplus_{2,19,10}(x, y) : z_2 = x - 23$ when $x = 43$

jaśtva sandhi

20. *jhalām jaś jhaśi* || 8.4.53 ||

Rule: non-nasal mutes, sibilants, aspirate followed by soft consonants (column 3, column 4) \rightarrow first replaced by corresponding column 3 letter.

General operator: $\oplus_{2,20}(x, y) = z = z_2y$ when $24 \leq x \leq 47, 24 \leq y \leq 33$

$\oplus_{2,20,1}(x, y) : z_2 = x + 5$ when $24 \leq x \leq 28$

- $\oplus_{2,20,2}(x, y) : z_2 = x$ when $x \in \{29, 30, 31, 32, 33, 44, 45, 46, 47\}$
 $\oplus_{2,20,3}(x, y) : z_2 = x - 3$ when $x = 34$
 $\oplus_{2,20,4}(x, y) : z_2 = x - 5$ when $x \in \{35, 37, 38\}$
 $\oplus_{2,20,5}(x, y) : z_2 = x - 7$ when $x = 36$
 $\oplus_{2,20,6}(x, y) : z_2 = x - 8$ when $x \in \{40, 41\}$
 $\oplus_{2,20,7}(x, y) : z_2 = x - 10$ when $x = 39$
 $\oplus_{2,20,8}(x, y) : z_2 = x - 11$ when $x = 42$
 $\oplus_{2,20,9}(x, y) : z_2 = x - 13$ when $x = 43$

cartva sandhi21. *khari ca* || 8.4.55 ||

Rule: non-nasal mutes, sibilants, aspirate followed by hard consonants (column 3, column 4, sibilants) -> first replaced by its corresponding column 1 or sibilants.

General operator: $\oplus_{2,21}(x, y) = z = z_2y$ when $24 \leq x \leq 47, 34 \leq y \leq 46$

- $\oplus_{2,21,1}(x, y) : z_2 = x + 18$ when $x = 25$
 $\oplus_{2,21,2}(x, y) : z_2 = x + 16$ when $x = 26$
 $\oplus_{2,21,3}(x, y) : z_2 = x + 15$ when $x = 24$
 $\oplus_{2,21,4}(x, y) : z_2 = x + 13$ when $x \in \{27, 28, 30\}$
 $\oplus_{2,21,5}(x, y) : z_2 = x + 11$ when $x = 31$
 $\oplus_{2,21,6}(x, y) : z_2 = x + 10$ when $x = 29$
 $\oplus_{2,21,7}(x, y) : z_2 = x + 8$ when $x \in \{32, 33, 34, 35\}$
 $\oplus_{2,21,8}(x, y) : z_2 = x + 3$ when $x \in \{36, 37, 38\}$
 $\oplus_{2,21,9}(x, y) : z_2 = x$ when $39 \leq x \leq 47$

parasavarṇa sandhi22. *anusvārasya yayi parasavarṇaḥ* || 8.4.58 ||

Rule: *anusvāra* followed by semi-vowels, mutes -> *anusvāra* replaced by the nasal equivalent of the second.

General operator: $\oplus_{2,22}(x, y) = z = z_2y$ when $x = 48, 15 \leq y \leq 43$

- $\oplus_{2,22,1}(x, y) : z_2 = 20$ when $x \in \{16, 17\}$
 $\oplus_{2,22,2}(x, y) : z_2 = y$ when $x \in \{15, 18, 19, 20, 21, 22, 23\}$
 $\oplus_{2,22,3}(x, y) : z_2 = y - 5$ when $24 \leq x \leq 28$
 $\oplus_{2,22,4}(x, y) : z_2 = y - 10$ when $29 \leq x \leq 33$
 $\oplus_{2,22,5}(x, y) : z_2 = y - 13$ when $x = 34$
 $\oplus_{2,22,6}(x, y) : z_2 = y - 15$ when $x \in \{35, 37, 38\}$
 $\oplus_{2,22,7}(x, y) : z_2 = y - 17$ when $x = 36$
 $\oplus_{2,22,8}(x, y) : z_2 = y - 18$ when $x \in \{40, 41\}$
 $\oplus_{2,22,9}(x, y) : z_2 = y - 20$ when $x = 39$
 $\oplus_{2,22,10}(x, y) : z_2 = y - 21$ when $x = 42$
 $\oplus_{2,22,11}(x, y) : z_2 = y - 23$ when $x = 43$

23. *torli* || 8.4.60 ||

Rule 1: dentals except *n* followed by *l* -> dentals replaced by *l*.

General operator: $\oplus_{2,23}(x, y) = z = z_2y$ when $x \in \{41, 38, 33, 28\}, y = 18$

- $\oplus_{2,23,1}(x, y) : z_2 = y$

24. *torli* || 8.4.60 ||

Rule 2: *n* followed by *l* -> *n* replaced by nasal *l* (i.e. *ṃl*).

General operator: $\oplus_{2,24}(x, y) = z = z_2y = z_{21}z_{22}y$ when $x = 23, y = 18$

- $\oplus_{2,24,1}(x, y) : z_{21} = 48, z_{22} = y$

4.3 C₃ Sandhi-s**ścutva sandhi**1. *stoḥ ścunāḥ ścuḥ* || 8.4.40 ||

śāt || 8.4.44 ||

Rule: [palatals followed by dentals, *s*] or [*ś* followed by *s*] -> second replaced by palatals or *ś* respectively.

General operator: $\oplus_{3,1}(x, y) = z = xz_3$ when $x \in \{39, 36, 29, 24, 19, 44\}, y \in \{41, 38, 33, 28, 23, 46\}$

$\oplus_{3,1,1}(x, y) : z_3 = y - 2$ when [$y = 46$] or [$x \neq 44, y \in \{41, 38\}$]

$\oplus_{3,1,2}(x, y) : z_3 = y - 4$ when $x \neq 44, y \in \{33, 28, 23\}$

ṣṭutva sandhi2. *ṣṭunāḥ ṣṭuḥ* || 8.4.41 ||

na padāntāṭṭoranām || 8.4.42 ||

Rule: *ṣ* followed by dentals, *s* -> dentals, *s* replaced by cerebrals, *ṣ* respectively.

General operator: $\oplus_{3,2}(x, y) = z = xz_3$ when $x = 45, y \in \{41, 38, 33, 28, 23, 46\}$

$\oplus_{3,2,1}(x, y) : z_3 = y - 1$

pūrvasavarṇa sandhi3. *jhayo ho'nyatarasyām* || 8.4.62 ||

Rule: non-nasal mutes followed by *h* -> *h* replaced by the aspirate letter (column 4) corresponding to the first non-nasal mute.

General operator: $\oplus_{3,3}(x, y) = z = xz_3$ when $24 \leq x \leq 43, y = 47$

$\oplus_{3,3,1}(x, y) : z_3 = x$ when $24 \leq x \leq 28$

$\oplus_{3,3,2}(x, y) : z_3 = x - 5$ when $29 \leq x \leq 33$

$\oplus_{3,3,3}(x, y) : z_3 = x - 8$ when $x = 34$

$\oplus_{3,3,4}(x, y) : z_3 = x - 10$ when $x \in \{35, 37, 38\}$

$\oplus_{3,3,5}(x, y) : z_3 = x - 12$ when $x = 36$

$\oplus_{3,3,6}(x, y) : z_3 = x - 13$ when $x \in \{40, 41\}$

$\oplus_{3,3,7}(x, y) : z_3 = x - 15$ when $x = 39$

$\oplus_{3,3,8}(x, y) : z_3 = x - 16$ when $x = 42$

$\oplus_{3,3,9}(x, y) : z_3 = x - 18$ when $x = 43$

chatva sandhi4. *śaścho'ti* || 8.4.63 ||

Rule: non-nasal mutes followed by *ś* which is in turn followed by a vowel, aspirate or *y, v, r* -> *ś* replaced by *ch*.

General operator: $\oplus_{3,4}(x, y) = z = xz_3$ when $24 \leq x \leq 43, y = 44, 1 \leq w \leq 17$

$\oplus_{3,4,1}(x, y) : z_3 = 36$

4.4 C₄ Sandhi-s**tugāgama sandhi**1. *che ca* || 6.1.73 ||

ānmānośca || 6.1.74 ||

dīrghāt || 6.1.75 ||

padāntādvā || 6.1.76 ||

Rule: vowel followed by *ch* -> *t* added.

General operator: $\oplus_{4,1}(x, y) = z = xz_4y$ when $x \leq 13, y = 36$

$\oplus_{4,1,1}(x, y) : z_4 = 41$

dhuḍāgama sandhi

2. *daḥ si dhut* || 8.3.29 ||
naśca || 8.3.30 ||
Rule: *ḍ* or *n* followed by *s* -> *dh* added.
General operator: $\oplus_{4,2}(x, y) = z = xz_4y$ when $x \in \{23, 32\}$, $y = 46$
 $\oplus_{4,2,1}(x, y) : z_4 = 28$

tugāgama sandhi

3. *śi tuk* || 8.3.31 ||
Rule: *n* followed by *ś* -> *t* added.
General operator: $\oplus_{4,3}(x, y) = z = xz_4y$ when $x = 23$, $y = 44$
 $\oplus_{4,3,1}(x, y) : z_4 = 41$

ṅamuḍāgama sandhi

4. *ṅamo hrasvādaci ṅamuṅṅityam* || 8.3.32 ||
Rule: Short vowel precedes *ṅ*, *ṅ*, *n* which is followed by vowel -> *ṅ*, *ṅ*, *n* get duplicated.
General operator: $\oplus_{4,4}(x, y) = z = xz_4y$ when $x \in \{21, 22, 23\}$, $1 \leq y \leq 13$, $u \in \{1, 3, 5, 7, 9\}$
 $\oplus_{4,4,1}(x, y) : z_4 = x$

4.5 C₅ Sandhi-s**svādi sandhi**

1. *etattadoḥ sulopo'koranaṅsamāse hali* || 6.1.132 ||
Rule: word *eṣaḥ* or *saḥ* followed by a consonant -> *visarga* (end *ḥ*) of first word dropped.
General operator: $\oplus_{5,1}(x, y) = z = y$ when $x = 49, 14$
 $\leq y \leq 47$, $X \in \{10+45+1+49, 46+1+49\}$
 $\oplus_{5,1,1}(x, y) = z = y$
2. *so'ci lope cetpādapūraṅam* || 6.1.134 ||
Rule: word *saḥ* followed by a vowel -> the final *visarga* of first word optionally dropped.
General operator: $\oplus_{5,2}(x, y) = z = y$ when $x = 49$, $1 \leq y \leq 13$, $X = 46+1+49$
 $\oplus_{5,2,1}(x, y) = z = y$
3. *lopaḥ śākalyasya* || 8.3.19 ||
Rule: final *v* or *y* preceded by *a* or *ā* and followed by a vowel, semi-vowel, nasal, column 3 or column 4 -> the *v* or *y* is dropped.
General operator: $\oplus_{5,3}(x, y) = z = y$ when $x \in \{15, 16\}$, $1 \leq y \leq 33$, $u \in \{1, 2\}$
 $\oplus_{5,3,1}(x, y) = z = y$
4. *oto gārgyasya* || 8.3.20 ||
Rule: *y* preceded by *o* and followed by a vowel, semi-vowel, nasal, column 3 or column 4 -> the *y* is dropped.
General operator: $\oplus_{5,4}(x, y) = z = y$ when $x = 15$, $1 \leq y \leq 33$, $u = 11$
 $\oplus_{5,4,1}(x, y) = z = y$
5. *hali sarveṣām* || 8.3.22 ||
Rule: *y* followed by consonant -> *y* dropped.
General operator: $\oplus_{5,5}(x, y) = z = y$ when $x = 15$, $14 \leq y \leq 46$
 $\oplus_{5,5,1}(x, y) = z = y$

The aphorisms presented above encompass four out of the five major *sandhi* divisions that exist in Sanskrit as per Pāṇini – vowel, consonant, *prakṛtibhāva* (no change and hence not dealt with here), *visarga* and *svādi*. The vowel *sandhi*-s have been extensively dealt with above, with all exceptions to main rules incorporated. In the other divisions, only the main *sandhi*-s have been covered. Furthermore, listing of the same aphorism twice was necessitated by the need for different general operators for different rules within the same aphorism.

It is noteworthy that the *sandhi*-s have not been presented under these five divisions, but in the order of the categories introduced in this paper. Furthermore, since the order of aphorisms is crucial to determining the sequence of firing of the rules, Pāṇini's numbering (given as aphorism number for each aphorism) has been maintained, albeit only within each category.

5. Conclusions

In spite of there being almost 2500 individual letter-level rules (Table 2), this new schema that directly maps the patterning in the Pāṇinian aphorisms in a simple and effective way, ensures that we arrive at a total of just 110 equations. Clearly, this is a computationally lean way of calculating the result of *sandhi* operations. The results represent a computational model to process a majority of the euphonic conjunctions in Sanskrit. The work also demonstrates the simplicity with which euphonic conjunctions can be handled by adopting Pāṇini's precise scheme for rule representation.

A main strength of this modeling approach is that it is deterministic, as against the probabilistic methods adopted till now for *sandhi* operations. Determinism is inherent in Pāṇini's *sandhi* rules, which indeed specify how *sandhi*-s are formed and not how they are broken up, and this determinism has been uniquely tapped and modeled in this work. Traditional AI methods such as hidden Markov models, which have hitherto been applied for Sanskrit processing [3-7], assume relevance in the *sandhi*-splitting approach in which there are inherent ambiguities, rather than in the *sandhi*-building approach which is modeled here.

The five main operators and all the 110 derived equations designed and presented in this work, form the immediate basis for directly realizing crucial applications of *sandhi*-processing such as subtext searching.

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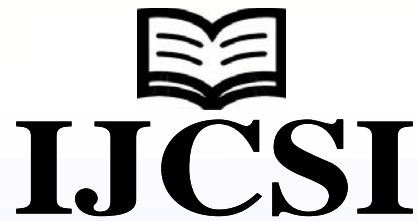
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