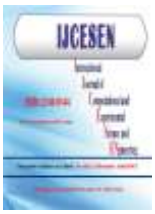
International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 11-No.3 (2025) pp. 4199-4227
http://www.ijcesen.com



ISSN: 2149-9144

Research Article

A Comprehensive Survey on Anaphora Resolution Algorithms and Related Tasks for Hindi and other Major Indian Languages

Chetan Agarwal[1]*, Kamlesh Dutta[2], Pardeep Singh[3]

[1]Computer Science and Engineering Department, NIMS Institute of Engineering and Technology, NIMS University Rajasthan, Jaipur (RAJ), INDIA
* **Corresponding Author Email:** chetanswadeshi@gmail.com - **ORCID:** 0000-0001-5550-9152

[2]Computer Science and Engineering Department, National Institute of Technology, Hamirpur (H.P.), INDIA
Email: kd@nith.ac.in - **ORCID:** 0000-0003-3197-2235

[3]Computer Science and Engineering Department, National Institute of Technology, Hamirpur (H.P.), INDIA
Email: pardeep@nith.ac.in - **ORCID:** 0000-0002-3534-4108

Article Info:

DOI: 10.22399/ijcesen.2573
Received : 23 March 2025
Accepted : 20 May 2025

Keywords

Natural Language Processing
Anaphora
Anaphora Resolution
Issues and Approaches for Hindi Discourse
Linguistic Knowledge Source

Abstract:

Recognizing the cognitive relevance and potential of improving the efficiency of several ***Natural Language Processing*** (NLP) applications, NLP researchers continuously have been striving to resolve the issue of ***Anaphora Resolution*** (AR) since long ago. Linguistic and cognitive evidence about the correct interpretation of anaphora have been studied by the researcher for a wide range of languages and computational models have been successfully built for languages having long history of research. In recent years, the issue of anaphora resolution is being addressed for low resource languages like Hindi as well, however the work reported in literature is either in nascent stages or it has been carried out with limited scope of real implementations. The goal of the current survey is to examine the anaphora resolution work that has been done for Hindi and related languages. The survey also aims to identify gaps and mechanisms for accelerating Hindi language research outcomes by utilising available technologies and customising or adapting them for the job. At first almost 450 research articles were collected on the basis of recursive searching of citations of anaphora resolution related literature published in last 20 years. Thereafter, on the basis of title and abstract analysis, 145 relevant articles were filtered and selected for study. Finally according to their work purpose were categorised into four categories; (i) previous survey, (ii) case study (iii) proposals for AR (iv) other related work.This research article provided (i) an elaborative and systematic review of research-works carried out so far in the field of AR for major Indian languages in general and for Hindi in particular, (ii) illustrated the use of linguistic knowledge sources in AR, (iii) study and analyzed 18 different prominent algorithms developed so far for AR in Hindi with four aspects: primary focus, approach, strengths and weaknesses, efficiency measure.***Conclusion:*** This paper presented a survey of anaphora resolution related research work carried out for Hindi and closely related languages and a comparative analysis of AR algorithms developed so far for Hindi with four key aspects. At last, on the basis of study and analysis, some research gaps also have been listed.

1. Introduction

1.1 Motivation

Anaphora resolution is one of the classical and most challenging problem in the field of natural language processing. Researchers have been attempting to resolve it for more than forty years, almost from the time of evolution of NLP applications itself [129]. Basically, **anaphora** is a linguistic expression that refers back to some previously mentioned entity and hence used to avoid repetition in the discourse. The process of identifying the entity which is being referred by the anaphora in consideration is known as **anaphora resolution** (Mohammadi et al. 2022).

Anaphora research is crucial from a number of perspectives [54, 55].

1) Anaphora representation is one of the most intricate aspects of language that has a significant impact on many issues. Crosslinguistic studies have shown that the variation in languages does not allow the development of a universal solution for anaphora resolution for all languages [41]. For example, the subject pronoun can be dropped in various languages such as Italian, Spanish and Hindi, whereas English mandate that subject, a grammatical term used to describe the nouns, pronouns, and noun phrases, to occur before the verb in a sentence. Many languages do not have specific reflexive or reciprocal expressions (Levinson 2000). Many languages in Southeast Asia lack third-person pronouns and some lack distinct personal pronouns, instead adopting titles (such as "honourable sir") [21]. Pronouns are also absent in various sign languages. Signs used to represent pronouns indicate traits of both personal pronouns and pointing gestures, therefore they cannot be classified solely as one or the other (Petitto 1987, Kimmelman 2009, 19, Trevor 2013).
2) Anaphora has long been thought of as one of the few parameters that can help us to understand the cognitive aspects of refferening expressions and functioning of the human mind and brain. Cognitive-based theories on the use of referring expressions make an assumption about the cognitive status of entities and these assumptions influence the choice of referring expressions from binding perspective. From anaphora resolution perspective, Givenness Hierarchy model [44], a cognitive theory-based model, highlighted the significance of anaphors for determining cognitive status from the binding perspective. According to the Givenness Hierarchy theory, pronouns and other referring forms convey information about the cognitive status of their referents in the addressee's mind as part of their lexical meaning. Pronominals refer to entities that the speaker expects the addressee to have in their working memory (activated). According to cross-linguistic studies within this model [45 , 46, Humnick 2009) a subset of pronominals is only allowed to refer to entities that are the focus of the addressee's attention. Another cognitive theory that had significant impact on the studies related to anaphora is Centering theory (Grosz et al. 1995) [43]. It has been widely used and supported by cognitive studies of pronominal anaphors as it can explain a variety of anaphoric occurrences. Other researchers [20, Posio 2016, Vergoossen 2021) also conducted studies focusing on cognitive evidence associated with the use of referring expressions.
3) Anaphora is considered to be such a complex phenomenon in any natural language that it cannot be resolved at a single layer. It has been demonstrated that anaphora interacts with pragmatic, semantic, and syntactic factors (Rudnev 2009). As a result, it has been instrumental in the implementation of NLP-related applications where understanding the relationship between all of these factors is essential to be resolved. Where, syntactic information is helpful in identifying constraints, semantic information is helpful in identifying preference for a particular referring expression. For example, partial semantically general anaphoric expressions tend to favour locally coreferential interpretations whereas, full, semantically specific anaphoric expressions tend to favour locally non-coreferential interpretation [54]. On the other hand, when a pronoun derives its meaning from the utterance's nonlinguistic context, or the context in which the speech act takes place, pragmatic processing is also required.
4) Researchers (Mitkov et al. 2007, Lahoti et al. 2022) have shown that anaphora resolution has the potential to enhance the overall performance of a number of NLP applications, whether it is used as an extra plug-in module or as a processing pipeline component. Its applications span from more modern ones like Sentiment Analysis (SA), Text Summarization (TA), etc. to more conventional ones like Question Answering (QA), Machine Translation (MT), Information Extraction (IE), etc. (Saha and Senapati 2022).

As a result of the great importance of anaphora resolution in several important applications, academics have worked to create a variety of methods for resolving anaphora in text.

Since various language resources like dictionaries, WordNet, corpus, etc., and language processing tools like, lexical analyzer, POS taggers, etc. are part and parcel for the success of NLP applications [28], much of the NLP tasks carried out and applications developed were for resource rich languages like western languages, specially English. While, on the otherhand, because of the linguistic complexity and various resource constraints, there hasn't been much development of NLP tasks for Asian or the Indian subcontinent languages and these languages are behind in this sector.

Analogously, on the same ground of lack of resources and pre-processing tools, limited

anaphora resolution related work has been carried out for low resource languages like Hindi. More specificaly, not enough comprehensive and detailed review work has been noticed in literature related to anaphora resolution task and approaches focused on Hindi or other closely related language. Current technological advancements in the field of NLP has shown greater promise of finding solutions for low resource languages as well. In the era of globalization and upsurge of digitization, the NLP related applications for low resource languages also find prominent place in the research domain.

Although, because of this change in scenario and recognizing the fact that Hindi is the most spoken language of India, with around one billion speakers across the globe [27]; (691 million speakers in India and 366 million speaker in rest of the world) alongwith the Indian government, several private organizations, business houses, research institutes and scholars in India as well as overseas are presently striving to provide NLP tools and applications for Indian languages (Lata et al. 2022b), nonetheless anaphora resolution is still an active research problem from Indian languages perspective.

Very few survey articles (Pal et al. 2012, Lakhmani and Singh 2013, Ahir et al. 2015 [4], Kukkar and Mohana 2016, Kaur and Kaur 2016 [64], Yadav et al. 2016 [168], Mahato et al. 2018, Shekhar and Kumar 2018, Lata et al. 2021) have been found in literature which covers anaphora resolution related work for Hindi and other Indian languages. Nither any of these is completely focused on Hindi or major Indian languages nor have been written with extensive detail. The recent advances in the NLP technologies and the use of deep learning models also has resulted in a shift of anaphora resolution approaches from rule based to machine learning and further deep neural networks; use of hand-crafted features to end-to-end deep learning-based approaches.

Therefore, this survey is motivated by the necessity of an elaborative review work dealing extensively with AR related work in Hindi and also to facilitate and update researchers about state-of-art work. The objective of this article is to provide a comprehensive and up-to-date survey of the field, given that the previous surveys for Hindi language were carried out earlier. To help the researchers engaged in anaphora resolution task for low resource language such as Hindi, the present article attempts to conduct comparative examination of numerous anaphora resolution-related tasks, algorithms developed for Hindi and other important Indian languages, summarize various issues related to anaphora resolution systems, such as methodology employed, algorithms implemented, or evaluation techniques used.

1.2 Contribution of the paper

The research work reported in this survey article shall be beneficial for NLP researchers in understanding the status of research for Hindi and making the informed decisions for the choice of approaches, corpus and relevant feature set in respect of an anaphora resolution problem. The main contributions of this paper are as follow: -

1. It explores research-works carried out so far in the field of AR from Hindi and some Indian languages perspective in detail and provides a systematic review of the same.
2. It identifies and illustrates the role of various linguistic knowledge sources in AR process from Hindi language perspective.
3. It provides a comparative examination of various existing AR proposals for Hindi, proposed by different researchers and ranging from fundamental rule-based to advanced deep learning approaches.
4. It identifies the research gaps of existing approaches and also provides a road map of the existing shape of the current research in anaphora resolution.

1.3 Structure of the Paper

Rest of the paper have been organized under the following sections. Section 2 begins with the introduction and explanation of the terms Anaphora and Anaphora Resolution with appropriate examples, and categorizes anaphora depending upon the classification criteria. Then it explores the importance of AR in NLP applications. Section 3 recapitulates AR related research work carried out for major Indian languages in last two decades. From work purpose point of view, entire related work has been divided into four categories; (i) previous survey, (ii) case study (iii) proposals for AR (iv) other related work. Section 4 illustrates the role of various types of linguistic knowledge sources in AR combined with various linguistic features like GNP, animacy, relevance and c-command etc. Section 5 presents a comparative study of prominent alogorithms proposed so far for AR in Hindi language and analyze these with four aspects: (i) primary focus, (ii) approach, (iii) strengths and weaknesses and (iv) efficiency measure. Section 6 discusses the challenges and future scope. The conclusion of this paper is summarized in Section 7.

2. Anaphora Resolution and its Importance in Nlp Applications

2.1 Anaphora Resolution

In order to keep up the interest in a discourse or a dialogue and to avoid the repetition of similar words, phrases, sentences, clauses, activities, events, etc. or even sometimes to refer or point out an anonymous entity in the text or extra textual entity, some specific words, abbreviated forms or another words or phrases are used in place of earlier mentioned entities in the text [1]. These specific words, phrases or abbreviated forms which are used to "point back" or “refer” some previous item or entity, are called an **anaphor**. The entity to which an anaphor refers, is defined as its **antecedent**. The process of determining the antecedent for a given anaphor is termed as **anaphora resolution**.

According to Mitkov (1999), the term **anaphora** is a compound word which consists of two separate words: **ana** and **phora**. Meaning of “**ana**” is “**back in upward direction”** while meaning of “**phora**” is “**act of carrying”,** hence “**anaphora**” means “**act of carrying back in an upward direction”**. Based on the notion of cohesion, Halliday and Hasan (1976) [49] defines that “anaphora is cohesion (presupposition) which points back to some previous item or entity”. Various types of anaphora have been defined in literature. Hirst (1979) [50]. Hirst (1981) [51], Mitkov (1999), Sukthanker et al. (2018), Lata et al. (2021) briefly outlined about widespread types of anaphora discussed in various AR related literature.

Sentences S1 and S2 of Ex 1 demonstrates the term anaphor and antecedent. Table 1 provides a list of anaphors with the corresponding anaphora type by realization, antecedent position, antecedent type and their antecedents appeared in sentences S1 and S2 of Ex 1.

Ex 1 S1: [यूक्रेन के राजदूत सर्गिय किस्लित्सिया**]1** ने दावा किया कि **[**रूसी सैनिकों**]2** ने **[**न्यूक्लियर प्लांट**]3** में काम कर रहे **[**कर्मचारियों**]4** की हत्या की है। **[**उन्होंने**]1** कहा कि **[**सुबह**]5 [**सेना के जवान**]2 [**जपोरिझिया प्लांट**]3** के पास पहुंचे और **[**वहां**]3 [**सुरक्षा-कर्मियों**]4** पर **[**गोलीबारी**]6** शुरू कर दी। **[**इस**]6 [**हमले**]6** में **[**चार लोगो**]4** की मृत्यु हो गयी है| **[**रूसी राजदूत**]7** ने कहा कि **[**एटमी प्लांट**]3** पूरी तरह काम कर रहा है और **[**वहां**]3 [**हमारे**]0** देश की कोई दखलअंदाजी नहीं है। (दैनिक भास्कर, 05/03/2022)

[yookren ke raajadoot sargiy kislitsiyaa]1 ne daavaa kiyaa ki [roosee sainikon]2 ne [nyookliyar plaanṭ]3 men kaam kar rahe [karmachaariyon]4 kee hatyaa kee hai. [unhonne]1 kahaa ki [subah]5 [senaa ke javaan]2 [japorijhiyaa plaanṭ]4 ke paas pahunche aur [vahaan]4 [surakṣaa-karmiyon]4 par [goleebaaree]6 shuroo kar dee. [is]6 [hamale]6 men [chaar logo]4 kee mrityu hee gayee hai . [roosee raajadoot]7 ne kahaa ki [eṭamee plaanṭ]3 pooree tarah kaam kar rahaa hai aur [vahaan]3 [hamaare]0 desh kee koii dakhala_andaajee naheen hai.

S2: [मुख्यमंत्री योगी आदित्यनाथ**]1** ने तीन **[**जिलों**]2** में पांच **[**चुनावी सभा**]3** करने के बाद **[**भाजपा के प्रदेश मुख्यालय**]4** में **[**मीडिया को संबोधित**]5** किया। **[**इस दौरान**]5 [**उनके**]1** साथ **[**डिप्टी सीएम मौर्य तथा शर्मा**]6** भी थे। **[**योगी**]1** ने कहा कि **[**हमने**]0** पांच वर्ष के **[**कार्यकाल**]7** में **[**प्रदेश**]8** के विकास का काम जारी रखा और **[**इसे**]8** दंगामुक्त बनाया। (अमर उजाला, 05/03/2022)

[Mukhyamntree Yogee Aadityanaath]1 ne teen [jilon]2 men paanch [chunaavee sabhaa]3 karane ke baad [bhaajapaa ke pradesh mukhyaalay]4 men [meeḍaiyaa ko sambodhit]5 kiyaa. [is dauraan]5 [unake]1 saath [ḍaipṭee seeem maury tathaa sharmaa]6 bhee the. [yogee]1 ne kahaa ki [hamane]0 paanch varṣ ke [kaaryakaal]7 men [pradesh]8 ke vikaas kaa kaam jaaree rakhaa aur [ise]8 dangaamukt banaayaa.

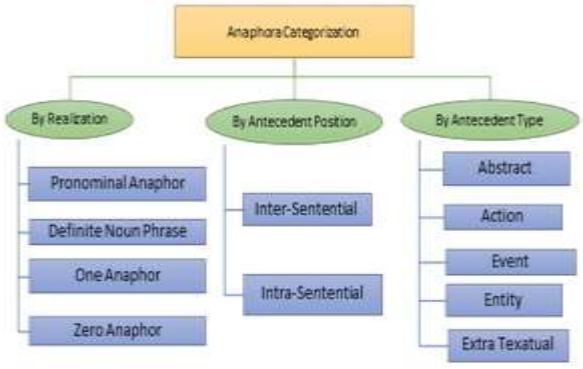


Figure 1. *Anaphora Categorization*

Table 1. *Anaphor and antecedent*

Sentence No.	Anaphor	Antecedent	Antecedent Position	Antecedent Type	Anaphora Realised
S1	किस्लित्सिया	यूक्रेन के राजदूत	Intra	Entity	Definite Noun Phrase
S1	उन्होंने	यूक्रेन के राजदूत	Inter	Entity	Pronominal
S1	सेना के जवान	रूसी सैनिक	Inter	Abstract	Indefinite Noun Phrase
S1	जपोरिझिया प्लांट	न्यूक्लियर प्लांट	Inter	Entity	Definite Noun Phrase

S1	वहां	न्यूक्लियर प्लांट	Inter	Entity	Pronominal
S1	सुरक्षा-कर्मी	कर्मचारी	Inter	Abstract	Indefinite Noun Phrase
S1	इस	गोलीबारी	Intra	Event	Pronominal
S1	हमला	गोलीबारी	Inter	Event	Definite Noun Phrase
S1	एटमी प्लांट	न्यूक्लियर प्लांट	Inter	Entity	Definite Noun Phrase
S1	वहां	न्यूक्लियर प्लांट	Inter	Entity	Pronominal
S1	हमारे	Not in Text	Not in Text	Extra Textual	Definite Noun Phrase
S2	इस	मीडिया को संबोधित	Inter	Event	Pronominal
S2	उनके	मुख्यमंत्री आदित्यनाथ	Inter	Entity	Pronominal
S2	योगी	मुख्यमंत्री आदित्यनाथ	Inter	Entity	Definite Noun Phrase
S2	हमने	Not in Text	Not in Text	Extra Textual	Pronominal
S2	इसे	प्रदेश	Inter	Entity	Pronominal

Depending upon the classification criteria, anaphora can be classified into different categories. Figure 1 depicts the anaphora categorization on the basis of three different criteria. From realization point of view, an anaphor might be categorized as: (i) Pronominal anaphor, (ii) Definite noun phrase, (iii) One anaphor and (iv) Zero anaphor, etc. Simillarly, on the basis of antecedent position, i.e. whether antecedent and anaphor both are in same sentence or in different sentence, an anaphor is categorized as: (i) Intra-sentential and (ii) Inter-sentential. On the basis of antecedent type to which an anaphor is referring, anaphors are categorized as: (i) Abstrct anaphor, (ii) Activity anaphor, (iii) Event anaphor, (iv) Entity anaphor and (v) Extra textual anaphor etc.

2.2 Importance of Anaphora Resolution in NLP applications

Recognising high relevance of anaphora resolution in a number of significant applications, ranging from traditional ones like Question Answering (QA), Machine Translation (MT), Information Extraction (IE), etc., to recent applications like Sentiment Analysis (SA), Text Summarization, etc., researchers put their efforts to develop various approaches to resolve anaphora in the text. This section briefly describes the role of AR in some of the NLP applications.

- **Information Extraction:** Given a machine-readable text (unstructured and/or semi-structured), process of automatic extraction of structured information or discovery of entity or relation is known as information extraction. Significance of anaphora resolution in the information extraction system have been studied by a number of researchers. Incorporating anaphora resolution, Wang et al. (2002) developed an information extraction system on the text in Chinese financial domain, which shown 91.4% precision. While exploring the application of AR in relation extraction, Kilicoglu et al. (2016) demonstrated that using heavily semantic approach of anaphora resolution is highly effective for biomedical literature. Wohiduzzaman and Ismail (2018) explored the utilization of anaphoric information in the recommendation system and developed a recommendation system for the Bangla News domain with the help of anaphora resolution. Ting et al. (2019) exploited the role of anaphoric information in named entity recognition and showed that the performance is enhanced of identifying entities for the person class.
- **Machine Translation:** Automated translation of text or speech using computer software is referred as machine translation (MT). Though, during the translation process, recognition of full phrases and their closest partners in the objective language is necessary, the mechanical replacement of words from one language to another language occasionally result in a good interpretation. While discussing about the issues of AR in MT and in other multi-lingual NLP applications, Mitkov (1999b) mentioned that the understanding of anaphora is fundamental for Machine Translation System to perform successfully. It is crucial to resolve the anaphoric relation while the translation into the languages which mark the gender of pronouns. Loaiciga and Wehrli (2015), Voita et al. (2018), Stojanovski and Fraser (2019) also explored the application of AR in machine translation. Fig 2 illustrates how anaphora resolution helps in improving the machine translation quality.
- **Question Answering:** QA is the another extensively used NLP application which entails creating systems that can answer questions in natural languages automatically. Comprising questions on a set of Wikipedia articles, Rajpurkar et al. (2016) developed a Stanford Question Answering Dataset (SQuAD), which included the concept of AR. Vicedo and Ferrández (2000) analyzed the effect of

pronominal AR to Question Answering (QA) systems and showed that QA performance improves by applying it. In an investigation of QA system, Bhattacharjee, et al. (2020) [15] found that the QA system with simple CR technique significantly outperforms the BERT baseline and produces an excellent F1 score of 89.8 . In an attempt of formalize bridging anaphora resolution as a question answering problem, Hou (2020) [56] propose a QA model to solve the task and showed that bridging anaphora resolution is helpful in some error analysis to verify the effectiveness of QA model.

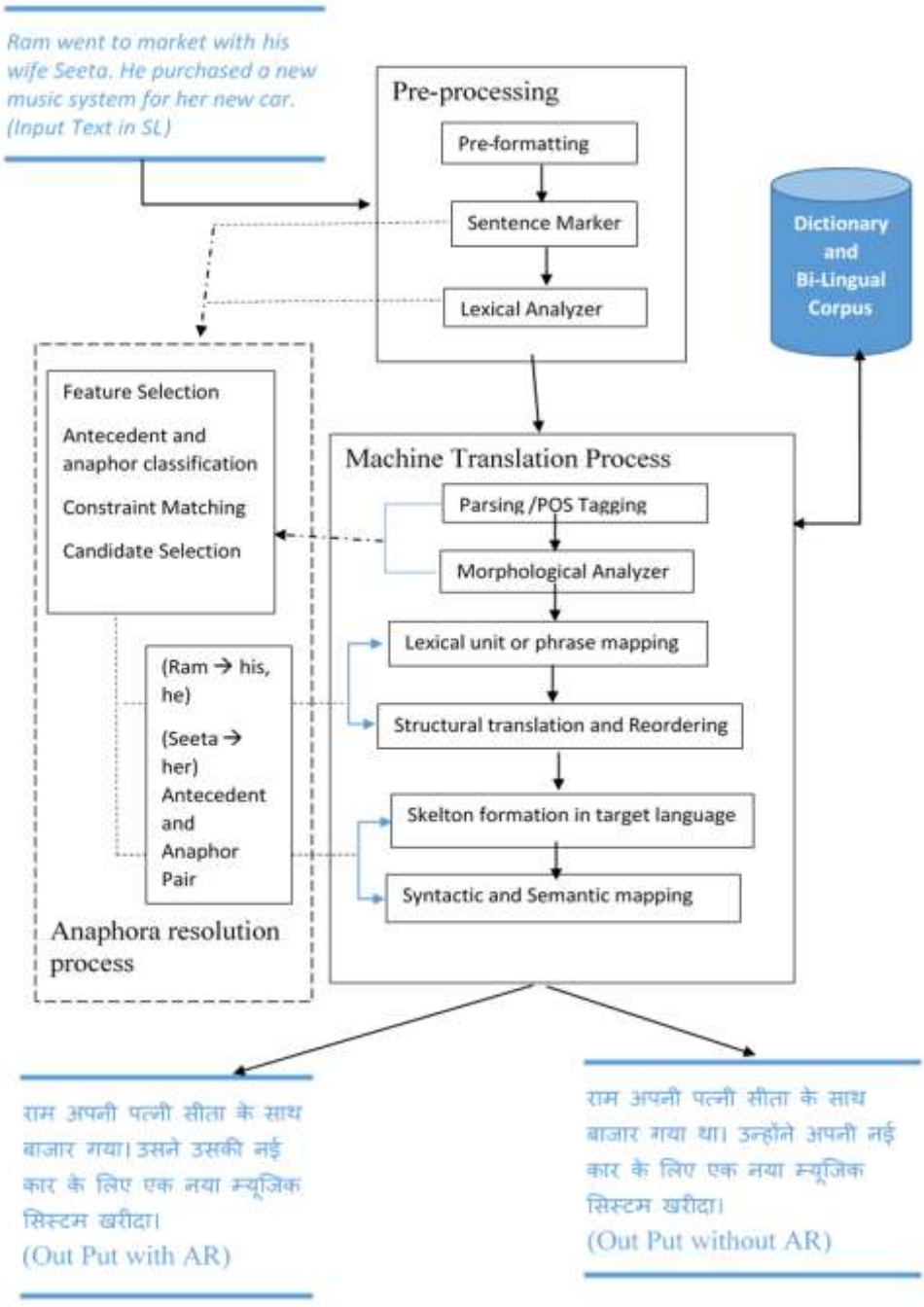


Figure 2. *Role of AR in Machine Translation*

- **Sentiment Analysis (SA):** Sentiment Analysis also known as Opinion Mining, has emerged as one of the important NLP application in recent time. Due to the uprise of social media and increasing trend of online shopping, SA has become the need of hour. The area assists in identifying a user's feelings from content such as a review, comment, and more. This job identifies the text's emotional connection, whether it be favourable, negative, or neutral. To detect and extract implicit knowledge in short and informal texts, Atkinson and Escudero (2022) proposed a new computation model for sentiment analysis applications. To find the motive behind users' movie reviews,

Jakob and Gurevych (2010) conducted a study on opinion mining using anaphora resolution. The methodology used was the rule-based CogNIAC AR algorithm. The findings showed favorable results regarding the extraction of opinion targets. Nithya (2019) also presented a deep briefing about how AR can be used in the real world towards Sentiment Analysis. Experimental results revealed the fact that performing the AR task is helpful to enhance the accuracy of sentiment analysis. The importance of determining the shell noun is conceived and expressed using FamilyShell mapping.

- **Text Summarization:** Process of extracting the important and recurring information and compressing long pieces of text to short one is referred as Text summarization. The purpose of text summarization is to produce a coherent and fluent summary that includes only main points outlined in the document. Automatic Cohesive Summarization with Pronominal Anaphora Resolution (*Antunes et al., 2018*) [7] was in which a new method called Anaphoric Expression Solver (AES) was presented for extractive text summarization that endeavors to generate more coherent summaries by unraveling pronominal anaphoric expressions. The AES method was able to achieve correct coreference substitution improving the cohesion of equivalent to 81% of the total evaluated. *Steinberger et al. (2007)* utilized the lexical and automatically extracted anaphoric information in LSA based text summarization.

3. Literature Review

Since, the research work on AR for European languages like English, German, French etc. had begun long before nearly about in 1970, a significant amount of work has been done for these languages. However, for Indian languages like Hindi, Punjabi, Marathi, Bengali, Tamil, etc., it began in 21st century only and very limited work has been carried out from this aspect. Sikdar et al.(2013), Devi et al. (2014) [33] discussed few impediments in this regard. Scarcity and inadequacy of parser, annotated data, POS taggers and other pre-processing tools required for development of efficient AR systems and approaches were considered as major hurdles. Hence from Hindi and other Indian languages perspective, much of work is expected to be carried out in this direction. One of major event for AR in Indian languages, "Shared task on NLP Tools Contest (ICON 2011)" was held in 2011.

Graph shown in figure 3 reveals the statics of work done on AR for Hindi and other very closely related languages. Data for this graph have been collected by going through the google search engine and on the basis of recursive searching of reference list of anaphora resolution related literature published in last 20 years. Statics figured out that about half of the work was carried out between 2011- 2015 and then again there was a fall between 2015-2020. Research papers collected for this statistical analysis, either proposed some anaphora resolution approach or have addressed some anaphora resolution related issues up to some extent or have presented survey.

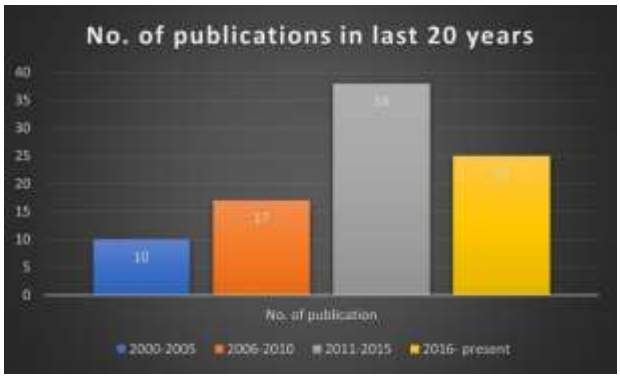


Figure 3. *Publication statistics of AR related work for Indian languages*

This section recapitulates AR related research work done in last two decades. From work purpose point of view, entire related work has been divided into four categories; (i) **previous survey**, (ii) **case study** (iii) **proposals for AR** (iv) **other related work**. Section 3.1 reports about survey or review papers which covered AR related work in Hindi. Through an exhaustive search of various research papers, their references list, research journals, google search and scholary articles etc., 10 survey papers were selected for discussion under this section. Section 3.2 briefs about various case study done by different researchers for AR in Hindi and other Indian languages. All the papers taken for consideration in this section, focused on some specific AR related issues like anaphora classification, identification, annotation, feature extraction, feature selection etc. Section 3.3 summarizes various AR algorithms proposed for a variety of Indian lanuages in last two decades. At the end, section 3.4 highlights the key facts of some other related work. Graph in figure 4 shows the share of different AR related work done for Hindi and other very closely related languages.

3.1 Previous Survey

Pal, Dutta and Singh (2012), Yadav et al. (2016) [168], Mahato et al. (2017, 2018), Patiyal, Singh and Dutta (2021) and many others like Lakhmani and Singh (2013), Ahir et al. (2016) [4], Kukkar and Mohana (2016), Kaur and Kaur (2016) [64] and Shekhar and Kumar (2018) have written survey papers with extensive detail on AR issues and approaches in Hindi. This section reports about survey or review papers which covered AR related work in Hindi.

Being dedicated mainly on pronominal anaphora, Pal, Dutta and Singh (2012) presented very first review work on AR in Hindi. In general, this review-work was focused on identifying different issues and challenges that are faced or need to be addressed in order to develop the computational models for Hindi. In particular, it focused on issues related to syntactic or semantic structure of Hindi and influence of cases on pronouns. While reporting on anaphora resolution for Hindi language, Lakhmani and singh (2013) tried to define constraint resources which can be used to form the foundation for anaphora resolution task. Kukkar and Mohana (2016) and Yadav et al. in (2016) [168] presented contribution of various researchers and worked out on various research gaps for the future researchers. Kukkar and Mohana (2016) described the definition, type, challenges, classification and various aspects of anaphora resolution approaches. In an another survey by Mahato, Thomas and Sahu (2017), various theoretical approaches of anaphora resolution have been discussed. They also discussed about suitability and utility of various resolution factors in different approaches. In another work, Mahato, Thomas and Sahu (2018) presented a survey on existing anaphora resolution systems like Guitar3.2, Mars, Javarap, Arkref etc. On the behalf of analysis and study of these different resolution systems authors tried to provide the basic ground for developing automatic anaphora resolution system.

Shekhar and Kumar (2018) gave a broad classification of various resolution approaches like rule based, corpus-based, discourse based etc. and mentioned about evaluation parameters. In recent, Patiyal, Singh and Dutta (2021) also have presented a very comprehensive review work on AR approaches. While describing about utilization of significant features to perform anaphora resolution task authors also discussed about evaluation metrics used in this field.

Table 2 lists out some of those survey or review papers and highlightes their key contributions from 4 aspects: (i) *AR issues addressed*, (ii) *AR systems reviewed*, (iii) *AR approaches discussed* and (iv) *scope of paper*.

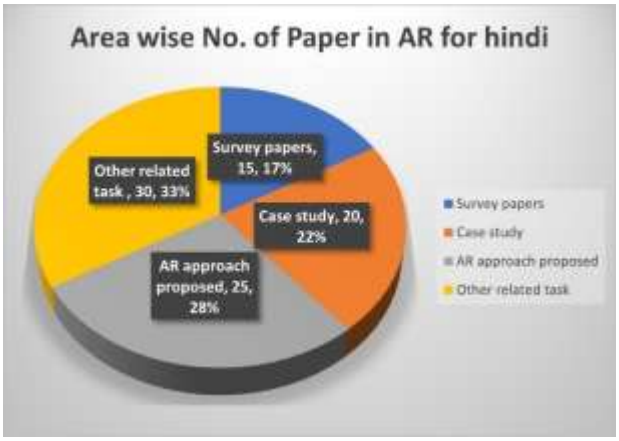


Figure 4. *Categorywise proportion of AR related work in Indian languages*

3.2 Case Study

Since AR is a very challenging and complicated task, researchers continuously strived to resolve the problem. They had different investigation, conducted experiments and analyzed different approaches to address the problem. They identified related issues, role of different features and other pre-processing techniques and tools in AR. Figure 5 depicts the different AR related case studies, conducted by various researchers for a varity of Indian languages. Remaining part of this section recapitulates key points of some of those important contributions.

(a) Model comparision: Singh, Lakhmani and Mathur (2014) and Lakhmani, Singh and Morwal (2014b) compared two computational models of AR. Both of the models were implemented for Hindi with a data set of a 5 children's story. These AR models were based on the concept of Lappin and Leass algorithm and concept of Centering algorithm respectively. They conducted the experiment with the intention of evaluating the impact of recency factor to the overall accuracy of correctly resolved pronouns and found that recency factor contributes for approximate 50% accuracy.

Table 2. *Survey papers on AR in Hindi*

Author	AR issues addressed	AR Systems reviewed	AR approaches discussed	Scope
Pal et al. (2012)	Influence of cases markers on pronouns syntactic/semantic structure of Hindi	MARS RAP MOA Jepthah	Modified Hobbs algorithm Rule based approach Gazetteer Method	Mainly focused on personal pronoun Studied how changes in the form of personal pronoun as

	Need of using standard information encoding	ARN		the case changes from direct to dative, genitive and other form.
Lakhmani and Singh (2013)	Need of Encoding in standard form Influence of cases markers on pronouns Gender and Number agreement	VASISTH ARN	Gazetteer techniques Hobbs Algorithm	Identified 4 constraint sources involved in AR Analyzed empirically the impact of these 4 constraint sources on AR in incremental faishon.
[4]	Syntactic and semantic structure of Hindi Identification of anaphoric and non-anaphoric phrases	GUITAR GIS	Gazetteer techniques Hobbs Algorithm Leppin and leass Algorithm	Discussed types of anaphora
Kukkar and Mohana (2016)	syntactic and semantic structure of Hindi Influence of cases markers on pronouns	COLING	Gazetteer method Tree search algorithm Modified Hobbs algorithm BFP algorithm	Identified research gaps and direction for future researchers Classified pronouns in Hindi Classification of conceptual AR approaches
[168]	Influence of cases markers on pronouns Gender and Number agreement	VASISTH PALINKA	Modified Hobbs algorithm Tree- CRF approach Hybrid approach	An extensive literature review on AR related work in Hindi Provided a publications statics on AR for Indian language
Mahato and Thomas (2017)	Factors for AR Identification of anaphoric and non-anaphoric phrases	GUITAR GIS VASISTH	Machine learning approach with semantic information and grammatical roles Discourse based approach Hybrid approach for pronominal anaphora resolution	Comparative study of computational models for AR Discussed factors useful for AR
Mahato and Thomas (2018)	Gender and Number agreement Data set classification	GUITAR BART MARS JAVARAP ARKREF	Discourse based approach Hybrid approach for pronominal anaphora resolution	Investigated prominent features employed in AR system Compared and categorized online available AR toolkits
Patiyal et al. (2021)	Feature identification and optimization Feature selection for AR Evaluation Metrics Data set classification	VASISTH ARN BART GUITAR LINGUA	Hobbs' modified algorithm A heuristic algorithm Hybrid approach to resolve Entity-pronoun	Recognized the correlation among various AR features Performed an empirical analysis of several AR models Identified prominent and required features for AR

(b) Parsing: Recognizing that how concept of ontology is capable to capture a specific real world aspect of a lexical items, Jain et al. (2013) [58] put a proposal to incorporate external knowledge with the ontology information for developing robust data driven dependency parsing techniques. Using morphological and contextual information of words, Dalal et al. (2006) [24] presented a Maximum Entropy (ME) based statistical model for POS tagging and chunking for Indian Languages. The tagger used a variety of features and worked fine for Bengali, Hindi, Telugu etc. Bharati et al.(2008) [12] proposed a constraint based 2-stage dependency parser.

(c) Feature set analysis: Based on genetic algorithms and using Multi-objective optimization techniques, Saha et el. (2011) tried to develop such optimize models which can optimize according to multiple metrics simultaneously. Arguing about the importance of properties of an antecedent in co-reference resolution, Singh and Dutta (2014a) investigated five different features (Nominal, Prepositional/ factua, Clausal, Adjectival and None) of an antecedent. They studied and analysed the impact of sentence structure of free word order languages in co-reference resolution and hence tried to figure out that up to what extent and on which feature of an antecedent researchers should emphasize for co-reference resolution. In another work of Singh and dutta (2015 b), emphasizing the need of evaluation of the impact of various features on AR, performed an empirical analysis. Out of seven most preferably tags used to employ for AR for Hindi, they considered two tags (Distance

marking and Nature of deixis). Experiment result shown that in case of feature 'Distance marking', approximate 65% antecedent are proximal and 35% antecedents are distal. Similarly, in case of feature 'Nature of dixies' approximate 33% antecedents are referred by pronouns and 67% antecedents are anticipated by demonstrative.

(d) Anaphora annotation: In an attempt of introducing a dependency annotation scheme for Indian languages, Begum et al. (2008) [10] developed a Paninian framework based and fully annotated large scale tree-bank for Hindi. Authors argued that Paninian framework is better suited to model the various linguistic phenomena manifest in Indian languages. Moreover, this annotation scheme is capable to handle some phenomenon such as complex verbs, ellipses, etc. In very recent work on AR related case stusy, Kaur, Goyal and Dutta (2022) [67] attempted to annotate Punjabi corpora with morphological information, POS tagging, and anaphoric links. They build a real corpus to be used for training and evaluation of Punjabi AR and proposed some additional features like animacy, NER, and pronoun type which will be used for machine learning module. Dakwale et al. (2012) [22], Jena et al. (2013) [59], Singh and Dutta (2014b), Singh and Dutta (2014d) and Singh and Dutta (2015a) also have been noticed as notable effort for anaphora annotation for Hindi.

(e) Antecednt claasification: For classification of demonstrative and personal pronouns without noun phrase antecedent in Hindi text, Dutta, Prakash and Kaushik (2010) proposed a probabilistic neural networks based application. In another work, Dutta, Kaushik and Prakash (2011) presented a machine learning approach for the classification of indirect anaphora in Hindi corpus.

3.3 Anaphora Resolution Proposals

Study and analysis of the AR related literature reveals that depending upon computational strategy used (Mitkov 1999, Mahto and Thomas 2015b), AR approaches are conceptually classified into two broad classes; (i) traditional or knowledge intensive or rule based approaches, (ii) alternative or knowledge poor (Statistical, Machine Learning and Deep Learning based approaches). Table 3 depicts some classification criteria of AR approaches.

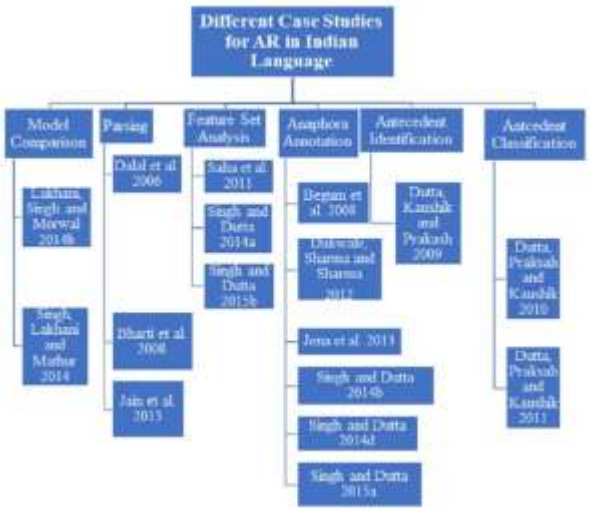


Figure 5. *Different Case Studies for AR in Indian languges*

Table 3. *AR algorithms classification criteria*

Criteria	Knowledge Rich or Rule based approaches	Knowledge Poor or alternative approaches
Preprocessing Stage	Requires manual Input	End to End automate
Labour	Labour intensive	Minimum labour
Parser requirement	Deep parsing	Normally shallow parsing
Syntactic and semantic knowledge	Deep knowledge	Minimal knowledge
Preprocessing of text	In-depth and full syntactic parsing	Basic semantic category information only
Efficiency depends	Exhaustic Rule base	Intensive Data set
Accuracy	Reasonable	Approximate

Researchers went into the deep of AR related concepts, issues, factors, approaches etc. They investigated and studied about the above mentioned points from linguistic point of view. After some required modifications they implemented it for Hindi and other Indian languages. This section is intended to provide a review for such most of the existing AR proposals for Indian languages from the following key aspects: (i) Linguistic knowledge source applied, (ii) Conceptual approach, (iii) Resolution Framework and (iv) Type of anaphora resolved primarily. Table 4 summrizes the review points for all discussed proposals. Graph in figure 6 shows the proportion of AR algorithms proposed for different Indian languages.

(a) Multi-lingual approaches: Devi et al. (2002) [29] put forward knowledge poor approach for resolving anaphora in Malayalam and Hindi

with limited syntactic knowledge and salience measurement. Devi et al. (2014) [33] incorporated agreement factors for analyzing the relationship between anaphors and their antecedents for Indian languages. Chatterji et al. (2011) [18] conducted data driven and statistical approach to determine reference of pronoun for Bengali, Tamil, and Hindi language using gender and number agreement with verb semantics. Based on multi-objective differential evolution, Sikdar, Ekbal and Saha (2016) proposed a joint model of feature selection and ensemble learning for AR in the resource-poor languages.

(b) Hindi: Prasad and Strub (2000) used discourse based approach employing salience ranking for resolving anaphora in Hindi. Agarwal et al. (2007) [3] implemented machine learning based approach with semantic information and grammatical roles for resolving the anaphora in Hindi. Dutta, Kaushik and Prakash (2008) developed rule based approach to resolve reflexive and possessive pronouns in Hindi by employing semantic information and gender agreement. Bhargav and Devi (2009) [14] used discourse based approach to resolve third person pronouns in Hindi. Dutta, Prakash and Kaushik (2011) described machine learning approach for studying indirect anaphora and classified them on basis of their semantic structure in a corpus based on Hindi language. Dakwale et al. (2013) [23] employed hybrid approach and improved the accuracy of anaphora resolution for Hindi language by bringing in number agreement, semantic analysis and NER factors. Lakhmani et al.(2014) used knowledge based approach and analyzed the role of Recency factor for resolving pronominal anaphora in Hindi. Mehla and Jangara (2015) attempted resolution of Event and Entity Anaphora for Hindi using semantic and NER information. Mahato and Thomas (2015) implemented hybrid approach for pronominal anaphora resolution in Hindi using semantic knowledge with gender and number agreement.

(c) Punjabi: Working on AR for Punjabi, Singh (2015) developed an AR system named as "PARS" for lexical anaphors. System was developed using POS tagged corpus and capturing the grammatical features of the language through the tagged labels. Kaur, Goyal and Dutta (2020) [65] and Kaur, Goyal and Dutta (2021) [66] presented an attempt to resolve anaphors in the Punjabi language using Machine Learning strategy. They tested the contribution of different features in resolving anaphors by training classifiers with different subsets of features. The features retrieved from the annotated corpus were used to train different classifiers. Authors claimed that results could be improved by using a larger corpus and adopting a rule-based strategy in conjunction with a machine learning approach.

(d) Marathi: Concentrating on resolving the anaphora in Marathi text, Khandale and Mahender (2019) and Khandale and Mahender (2021a, 2021b) presented AR approach, using the gender and the number agreement as well as the animistic knowledge.

(e) Telugu: To resolve speaker-hearer mentions and plural mentions in conversation, Annam, Koditala and Mamidi (2019) [6]build an AR system for Telugu dialogues. The system employed few handcrafted features appended to the word embeddings, focusing on semantic features.

(f) Sanskrit: At the best of knowledge and study of literature, Jha et al. (2008) [60] presented first AR algorithm for Sanskrit as a workable solutions. Focusing only on pronominal anaphors, algorithm was developed as a part of a larger Sanskrit analysis system. By exploiting the morphological richness of the language, Pralayankar and Devi (2010) presented an AR algorithm for Sanskrit. Implementing computational grammar, algorithm identified different types of pronominal and its antecedents in Sanskrit. In an another attempt for AR in Sanskrit and focusing on lexical anaphors, Gopal and Jha (2011) [42] developed an AR system named as "SARS". To determine the antecedents of anaphors, system exploited the grammatical features of the language and took the POS tagged Sanskrit text as input. Various morphological features were attached with the words of input text.

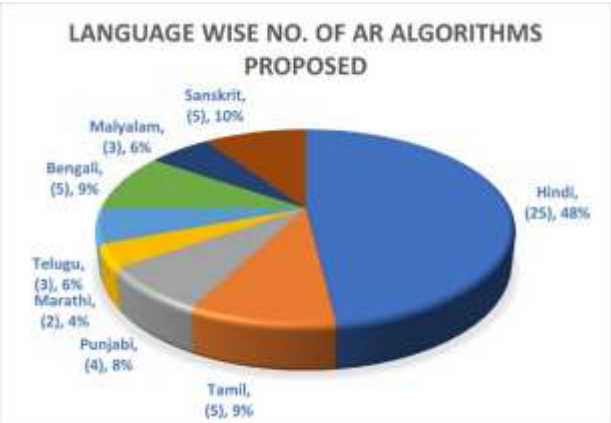


Figure 6. *Proportion of AR algorithms for Indian languages*

Table 4. *Summary of AR approaches proposed for Indian languages in last 20 years*

Author	Applicable to Languages	Linguistic Knowledge Source	Resolution Framework	Conceptual Approach	Anaphora type in focus
Prasad and Strube (2000)	Hindi	Syntactic Semantic	Centring theory based Relative salience S-list ranking framework	Rule based	Pronoun
[29[	Malayalam Hindi	Syntactic And Morphological	Sequential elimination of inappropriate antecedents	Rule based	All referentially dependent elements
[3]	Hindi	Semantic	Semantic analysis based constraint matching method for noun-pronoun pairs	Machine learning approach	Pronoun
[14]	Hindi	Sementic and Discourse knowledge	S-List based ranking method	Statistical	First, second and third person pronouns
Shobha et al. (2011)	Hindi	Syntactic and Morphological knowledge	Combination of salience factors from Lappin and Leass (1994) and where named entity and ontology from Sobha (2008), for Pronominal resolution and CRFs based machine learning approach.	Statistical	Pronominal and Non-pronominal co-reference resolution
[18]	Bengali Hindi Tamil	Syntactic and Morphological knowledge	CRF tree for markable identification and Decision Tree Algorithm to determine the links between markables	Statistical or Data driven approach	Pronoun reference
[23]	Hindi	Syntactic and Semantic knowledge	Dependency structures for simple anaphoric references, and decision tree classifier for more ambiguous references	Hybrid of rule-based (for simple anaphoric references) and then a decision tree classifier for remaining unresolved references	Entity-pronoun references
Sikdar et al. (2013)	Bengali	Syntactic and Discourse knowledge	CRF based classifier for mention detections	Data driven approach	All mentions defined in datasets based on the gold annotations
[33]	Bengali Hindi Tamil	Syntactic and Morphological knowledge	CRF based machine learning technique	Data driven approach	Nouns and pronouns
Lakhmani et al. (2014a)	Hindi	Syntactic Semantic and Discourse knowledge	Gazetteer Method to classify the elements and recency as a baseline factor and animistic knowledge for system learning	Data driven approach	Pronominal resolution
Mahato and Thomas (2015b)	Hindi	Syntactic knowledge	Preprocess and analyze the output from Treebank and store the tokens category wise Identification pronouns and locates the candidates for antecedents to resolve anaphora	Data driven approach	Pronominal anaphora
[2]	Hindi	Syntactic and Semantic knowledge	Paninian grammar based heuristic model Incrementally adding different syntactic, semantic and discourse features with	Rule based approach	Entity pronoun references

Author	Applicable to Languages	Linguistic Knowledge Source	Resolution Framework	Conceptual Approach	Anaphora type in focus
			optimal combination		
Mujadia, Gupta and Sharma (2016)	Hindi	Syntactic and Semantic knowledge	Language specific rules and pronominal placement for pronominal identification Paninian dependency grammar and proximity of events for resolution	Data driven approach	Event Anaphora Resolution
Kukkar and Mohana (2016)	Hindi	Syntactic knowledge	Based on finding the gender and number agreement.	Rrule based approach	Pronominal anaphora
Singla and Kumar (2017)	Hindi	Syntactic knowledge	Language specific rules and pronominal placement for pronominal identification Paninian dependency grammar and proximity of events for resolution	Rule based approach	Entity Resolution Five types of pronominal forms
Singh and Joshi (2019)	Hindi	Syntactic knowledge	Hidden Markov Model to POS tag the dataset and cases for the identification of preferred noun. Centering algorithm for identification of pronoun and its referents.	Rule based approach	Pronoun
Tewani (2020)	Hindi	Syntactic knowledge	Using Number Agreement and Animistic Knowledge	Rule based approach	Pronominal anaphora
[66]	Punjabi	Syntactic knowledge	Shallow Parser for POS taggings and GNP information of NPs Animacy, NER, Pronoun type features to link anaphors with entities Different subsets of features of annotated corpus to train different classifiers Ensemble classifiers to evaluate the Precision, Recall, and F-Score.	Machine Learning approach	Pronoun Resolution
[6]	Telugu	Syntactic knowledge	Shallow parser for extracting features, Feature vector generator to produces the word embeddings Neural network model to predict the antecedent mention of an anaphora	Deep Learning approach	Pronouns

3.4 Other Related Works

This section highlights the key facts of some other related work.

Work of Bharti et al. (1993), 29, Prasad (2003), Sinha and Thakur (2005a, 2005b) and Dutta et al. (2009) provides a great insight detail from anaphora resolution perspective for Hindi language.

While working on the development of a Natural Language Interface for Indian languages, Bharti et al. (1993) discussed and addressed the issues of reference and ellipsis as one of the major issue of AR. Continuing the trend, another significant work on AR has been done by Devi and Patnaik (2002) [29]. Based on exploration and employment of the morphological richness feature of Hindi and other Indian languages, they designed a multi-lingual anaphora resolution system "VASISTHA". In her Ph.D. thesis work, Prasad (2003) also focussed on similar trend i.e. zero pronoun or ellipsis. In her PhD thesis, she tried to identify and formulate the constraints on the generation of referring expressions with special reference to Hindi. Giving significant contribution, Sinha and Thakur (2005a, 2005b) addressed one another important issue of anaphora resolution named as divergence. In this

work, authors have pointed out about the different types of translation patterns, constructions and translation divergences between Hindi and English machine translations with a view of identifying the potential topics for translation divergences. Realising the need of addressal of divergence issues for quality machine translation, Dutta et al. (2009) also has made valuable effort. Primarily emphasizing on different aspects of pronominal divergence, authors illustrated about the effect of divergence on AR in English Hindi machine translation and presented some applications and benefits of pronominal divergence used in anaphora resolution. Sinha (2002) developed a corpus-based account for AR in Hindi. Singh et al. (2014) presented an enhanced annotation scheme on Emille corpus for indirect anaphora in Hindi. The annotation scheme is enhanced with the semantic information for indirect anaphora. Results of the experiments performed with automated classification using machine-learning approaches shown that the semantically enhanced annotation is a rich source of information for language understanding and hence for AR. Dutta et al. Machine Learning for Indirect Anaphora in Hindi generation systems and for conducting data oriented research.

On the basis of corpus based study, Singh and Dutta (2014) presented an approach for annotating indirect anaphora for Hindi. They extracted ten tags from literature. Seven tags out of these ten tags were annotated manually using Botley's annotation scheme [16]. They annotated 1540 demonstrative pronouns from EMILEE corpus. Authors stated this annotation scheme as an extension of work by Dutta et al. (2011). The methodology adopted for annotation purpose considers that demonstrative pronouns are understood in terms of an unordered paradigmatic set of five distinctive features as listed below: -

(i) Recoverability of Antecedent
(ii) Direction of Reference
(iii) Phoric Type
(iv) Syntactic Function
(v) Antecedent Type

On the basis of above features and 10 tags, an antecedent is classified as Recoverable and Non-recoverable. Further on, recoverable antecedent can be classified as Directly Recoverable and Indirectly Recoverable.

3.5 Role of Linguistic Knowledge in Anaphora Resolution

Since, AR is crucial for almost all kinds of NLP applications and is one of the most tedious task, it needs intensive level of knowledge and expertise about languages, grammar and language processing techniques. Although, it is quite clear that either individually or in combination, resolution process may need to involve different linguistic knowledge sources like syntactic knowledge, semantic knowledge, morphological knowledge, discourse knowledge and pragmatic knowledge etc., but however in available literature, no formal research or systematic study has been noticed that analyses or compares the role of various knowledge sources. Another important fact is that though depending upon the different features of language in consideration, different knowledge sources may have different level of importance in resolution procedure but no study has been noticed which can reveal the share or can rank or can define the sequence of applying the individual or combined knowledge source for efficient resolution procedure. A general analysis reveals that syntactic knowledge should be first and foremost source to be applied. Another fact is that for the morphologically rich languages like Hindi morphological knowledge may be crucial for resolution.

Figure 7 gives a brief look about association of various language features with different linguistic knowledge sources involved in AR process. For instance, combining syntactic knowledge with POS tagging and extracting gender, number and person features may be beneficial for AR. Similarly, extraction of animacy, relevance and C-command constraint features can be combined with semantic knowledge source.

Section 4.1 to 4.4 illustrates the role of various types of linguistic knowledge sources in AR combined with various linguistic features like GNP, animacy, relevance and c-command etc.

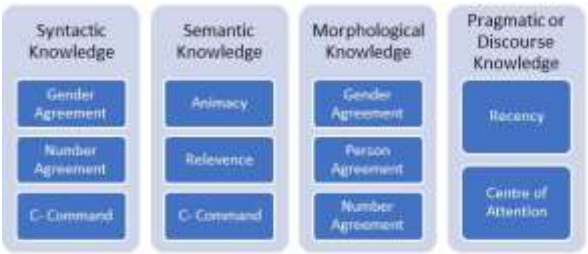


Figure 7. *Using Linguistic Knowledge Sources for resolving different anaphora resolution issues*

3.6 Syntactic Knowledge

Ex 2 S1: [महाभारत] के [युद्ध] में [श्री कृष्ण] [**अर्जुन**] के केवल [सारथी] ही नहीं बने अपितु [**उसका**] समुचित [मार्गदर्शन] भी किया |

(Mahaabhaarata yuddha mein krishana Arjuna ke kewala saarthee hi nahin bane, apitu uskaa samuchita maargadarshana bhee kiyaa |)

In S1 of Ex 2, "श्री कृष्ण" and "अर्जुन" are two possible antecedents for pronoun "उसका". But the syntactic knowledge of Hindi sentence reveals that entity "कृष्ण" is at the place of subject in the sentence, while "अर्जुन" is at the place of object, so from the syntactic structure of the sentence, it is obvious that "अर्जुन" got the guidance (मार्गदर्शन) from "श्री कृष्ण", i.e. It is clear that pronoun "उसका" is referring to "अर्जुन".

3.7 Semantic Knowledge

Ex 3 S1: [कृष्ण] ने [**दुर्योधन**] के सामने शांति-स्थापना के [**प्रस्ताव**] रखे पर [**उसने**] [**उन्हें**] अस्वीकार कर दिया |

(Krishana ne durayodhana ke saamne shaanti-sthaapanaa ke prastaav rakhen para usne unhen asweekaara kara diyaa |)

S2: [**कृष्ण**] ने [**दुर्योधन**] के सामने शांति-स्थापना के [प्रस्ताव] रखे पर [**उसने**] [**उन्हें**] बंदी बनाने का आदेश दिया |

(Krishana ne durayodhana ke saamne shaanti-sthaapanaa ke prastaav rakhen par usne unhen bandi banaane kaa aadesha diyaa |)

Since, syntactic structure of sentences S1 and S2 of Ex 3 are quite similar, therefore on behalf of syntactic knowledge, it is difficult to determine that in S1, pronoun "उन्हें" is referring to "शांति-स्थापना के प्रस्ताव", while in S2, pronoun "उन्हें" is referring to "कृष्ण". But here semantic knowledge intimates to us that phrase "अस्वीकार कर दिया" should be related to the rejection of some logical object like proposal, offer, etc., or some physical object like gift etc., while the phrase "बंदी बनाने का आदेश दिया" may be related to arrest order of some living entity. Hence use of semantic knowledge may enable us to determine that pronoun "उन्हें" in S1 is referring to "शांति-स्थापना के प्रस्ताव" while in S2, it is referring to "कृष्ण".

3.8 Morphological Knowledge

Ex 4 S1: [**अर्जुन**] ने बहुत लगन से [धनुर्विद्या] सीखी | यहाँ तक की [**वह**] [चक्रव्यूह] भी तोड़ सकता था |

(Arjuna ne bahuta lagana se dhanuravidya seekhee | yanhaan taka ki vaha chakravyooha bhee toda saktaa thaa |)

S2: यघपि [**सुभद्रा**] में भी [धनुर्विद्या] कौशल था | परन्तु [**वह**] [चक्रव्यूह] नहीं तोड़ सकती थी |

(Yadyapi subhadraa mein bhi dhanuravidyaa kaushala thaa paranatu vaha chakravyooha nahi toda saktee thee |)

Though it is clear that in sentence S1 of Ex 4, pronoun "वह" is referring to "अर्जुन" while in sentence S2 pronoun "वह" is referring to "सुभद्रा", but the gender of "अर्जुन" and "सुभद्रा" cannot be determined on the basis of pronoun "वह" itself. Here in sentence S1 and S2 morphological knowledge of verb "सकता था" and "सकती थी" reveals that gender of pronoun "वह" in sentence S1 and S2 is masculine and feminine.

3.9 Discourse Knowledge

Ex 5 S1: **[अर्जुन]**$_i$ ने **[**कृष्ण**]** से **[**मदद**]** लेने की सोची |

(Arjuna ne krishan se madad lene kee sochee |)

S2: [**उसे**] [कृष्ण] से मदद मिलने की पूरी आशा थी |

(Use krishana se madada milane kee pooree aashaa thee |)

S3: [**अर्जुन**] [कृष्ण] के पास गया और [**वह**] खुश था |

(Arjuna krishana ke paasa gayaa aura vaha khush thaa |)

In Ex 5, from S3 alone, it is not obvious that to which entity (अर्जुन or कृष्ण) pronoun "वह" is referring. However, knowledge of discourse i.e. knowledge of scenario of Mahabharata battle and relationship between Lord Krishna and Arjun, makes ensure that in S3 pronoun "वह" is referring to "अर्जुन". Similarly, appling pragmatic knowledge in combination of information from S1 and S2, it can be ensured that in S3 pronoun "वह" is referring to "अर्जुन".

3.10 Anaphora Resolution Approaches in Hindi

Various researchers working in the field of NLP and related area have given different algorithms for AR. This section presents a study of prominent alogorithms proposed so far for AR in Hindi language and analyze these with four aspects: *(i) primary focus, (ii) approach, (iii) strengths and weaknesses and (iv) efficiency measure.* As mentioned in section 3.3, AR algorithms are broadly classified into three broad categories, viz. Rule based approaches, Corpus based approaches and Deep learning approaches, section 5.1, 5.2 and 5.3 discusses about rule based, corpus based and deep learning based algorithms respectively.

3.11 Knowledge rich or Rule based approaches

3.11.1 Centring theory

Being inspired by the central idea of centring theory and results revealed by cross linguistic research, Prasad and Strube (2000) investigated anaphoric references in Hindi. They proposed a general method for determining C f -list ranking factors and applied this method with BFP algorithm and the S-list algorithm to pronoun resolution in Hindi texts.

(a) Primary focus: In their investigation on anaphoric reference in Hindi, Prasad and Strube (2000) particularly focused on the use and interpretation of third person personal pronouns to realize anaphoric relationships between noun phrases.

(b) Approach: According to the centring theory proposed by Grosz et al. (1995) [43], discourse entities (evoked by some utterance in a discourse) are comprised of as a list of forward-looking centres (the C f-list). After that entities of C f-list are ranked according to their salience. The anaphoric relationships in the local discourse segment are dependent on the C f -list ranking. Prasad et al. investigated such ranking factors for Hindi and proposed a method for determining these ranking factors. This approach represents arguments as the sentences containing them, and classifies connectives in terms of their expected collocation with their arguments in sentences and paragraphs.

(c) Strengths and weakness: Experiment result shown that BFP algorithm cannot be successfully implemented for pronoun resolution in Hindi. In particular, for morphologically rich languages like Hindi, S-list ranking can be applied straightforwardly.

(d) Efficiency measure: After proper investigating and determining the C f-list ranking criteria for Hindi, on the basis of notion of relative salience for pronoun resolution, 72.58% accuracy was measured for BFP alogorithm while 89.24% accuracy was reported for S-list algorithm. Major part of incorrect resolution was constituted by ambiguous analysis and for both algorithms.

3.11.2 Multilingual system VASISTH

A multilingual system VASISTH, which was capable to resolve anaphora and to handle ellipsis and gaps in two different languages namely Malayalam and Hindi, was proposed by Devi and Patnaik (2002) [29].

(a) Primary focus: This system resolves all referentially dependent elements such as pronominal, non-pronominal, gaps and ellipsis.

(b) Approach: Unlikely to other concurrently available resolution system, VASISTH explore the morphological richness of the languages and hence makes limited use of syntax and parsing.

(c) Strength and weakness : In contrast to other AR system, VASISTH is a multilingual system, which can handles two different languages, Malayalam and Hindi in its original version. It can easily be extended to handle other morphologically rich languages. The limitation of this work is that it uses only syntactic knowledge and does not use any world knowledge for resolution.

(d) Efficiency measure : When algorithm of resolution component is used for Hindi data, it yielded a success rate of 82%. Authors reported 93% success in pronoun and one-pronoun resolution and interpretation of gaps, and 96% success in the case of reflexive and ellipsis both.

3.11.3 Modified Hobbs algorithm

Dutta, Kaushik and Prakash (2008) presented an application of Hobbs algorithm (Hobb 1976). Hobbs algorithm is a syntactic rule based algorithm and manually parsed sentences are given as input to algorithm.

(a) Primary focus: Authors tailored the Hobb's algorithm to make it suitable for resolving pronominal anaphora in Hindi language. The algorithm has been adapted for Hindi language taking into account the roles of subject, object and its impact on anaphora resolution for reflexive and possessive pronouns.

(b) Approach: This algorithm makes use of syntactic information rather than semantic information and took into account the roles of subject, object and its impact on anaphora resolution for reflexive and possessive pronouns. Algorithm takes as input surface parse tree of the sentence and chooses a suitable NP as an antecedent of a pronoun **P** as output. The resolution procedure traverses full parse tree starting from the pronoun looking for noun phrases that could be possible antecedents and adding them to a list of candidates left to right breadth-first in the sub tree subject to the constraints defined by the algorithm.

(c) Strength and weakness: Authors stated that the algorithm was tested for limited set of sentences and experiments shown that the algorithm has some limitations. Inclusion of

semantic information might be helpful to overcome these limitations. Algorithm achieved good enough accuracy for fixed word order languages (like English and Chinese with SVO structure) but in case of free word order languages (like Hindi and other Indian languages with SOV structure) accuracy fall down.

3.11.4 S-List algorithm

Overcoming to the limitation of S-list algorithm proposed by Prasad and Strube (2000) and their by improving its performance, Bhargav and Sharma (2009) [14] introduced a new knowledge rich approach.

(a) Primary focus: This approach works on grammatical framework for extracting the grammatical roles and resolves the first and the second person pronouns.

(b) Approach: Rather than considering all the entities into a single list as in previous S-list algorithm, authors proposed the use of two separate S- lists; one for the discourse entities of the present utterance and another for the entities of the previous utterances. To deal with the long and complex sentences, algorithm employes extended model of centering theory based the S-List algorithm [63] and divides complex sentences into smaller utterences.

(c) Strength and weakness: This algorithm is capable to overcome some of S-list algorithm limitations. Another point in favour of this algorithm is that it is able to determine the antecedents for the first and second person pronouns just with the help of the verbs and their modifiers.

(d) Efficiency measure: Experiment results shown an 77.45% accuracy in aggregrate for first, second and third person pronoun, where as if third person pronouns are considered separately from first and second person pronouns, then accuracy is 74.69% and 91.58% respectively. Results shown that for first and the second person pronouns results are very encouraging, i.e. first and the second person pronouns should be considered separately.

3.11.5 Gazetteer method based classification

(a) Primary focus: Based on Gazetteer method and with a prime focus on pronominal anaphora resolution, Singh, Lakhmani and Morwal (2014) presented a computational model of anaphora resolution for Hindi.

(b) Approach: Using two factors, namely animistic (always represent living and non-living things) and recency (describes that the referents mentioned in current sentence tends to have higher weights than those in previous sentence), Gazetteer method creates different lists for different elements and then applies some operations to classify these elements present in the lists. In this way, Gazettes are utilized to supply external knowledge to learners, or to supply data with a training source. As mentioned above, this system creates lists of animistic pronoun (pronoun that refers to living things), animistic noun (nouns which represent living beings), non-animistic pronoun (pronoun that refers to non-living things) and non-animistic noun (noun that represent non-living beings) and the last list of middle animistic pronoun (pronoun that refer to both living and non-living things). This external knowledge helps the system in resolving anaphors.

(c) Strength and weakness: The Gazetteer method gives very fast result and accuracy depends upon completeness of the Gazetteer used. Beside of recency and animistic factor, consideration of number and gender agreement also increases the accuracy of system.

(d) Efficiency measure: On the basis of experiments, conducted on three different types of data sets, authors analyzed the contribution of recency and animistic factor to the overall accuracy of correctly resolved pronouns. Experiment result shown that contribution of recency and animistic factor to the overall accuracy was respectively 63%, 65% and 83% for data set 1, 2 and 3.

3.11.6 Paninian grammar based heuristic model

(a) Primary focus: To resolve entity pronoun references, Agarwal et al. (2015) [2] presented a heuristic model of AR for Hindi dialogue. This heuristic model employed and explored the Paninian based dependency structures as a source of syntactic and semantic information. The model was developed by using a rule based AR approach, in which different syntactic, semantic and discourse features were added with optimal combination in incremental manner.

(b) Approach: In this approach, resolver requires the output of full parsed, analyzed and subtopic boundary identifier in SSF format. The mention detection or anaphora determination step is not done by anaphora resolution module but it is triggered when shallow parser gives pronoun as POS tag for particular word in given dialogue.

For the identified mention pronoun, AR module tries to find the antecedent.

(c) Strength and weakness: Use of subtopic boundary within Paninian dependency framework, reduces the search space for antecedent identification and also gives a chance to highly possible referents of same subtopic. Due to scarcity of anaphora annotated corpus in Hindi, experiment was not conducted on user-system interaction data.

(d) Efficiency measure: Experiment result shown 27.16% accuracy with shallow features. When Shallow features were added with Panian grammar accuracy increased to 45.5%. Accuracy raised to 52.25% with addition of animacy & named entity features and reached to 59.58% with subtopic boundary feature.

3.11.7 Rule based approach

(a) Primary focus: Singh and Joshi (2019) presented a rule based approach to identify different types of anaphora and its antecedents for Hindi.

(b) Approach: As a pre-processing step, Hidden Markov Model was used for POS tagging of the dataset while cases were used for the identification purpose of preferred noun and centring algorithm for identification of pronoun and its referents.

(c) Strength and weakness: The system was not able to correctly identify the segments which had similar nouns head.

(d) Efficiency measure: Authors claimed that out of 500 noun-pronoun pairs, 405 pairs were correctly resolved, giving an accuracy of 81%.

3.11.8 Number, gender and animistic feature based approach

(a) Primary focus: On the basis of limited knowledge of the language, Tewani (2020) proposed an another approach for pronominal anaphora resolution in Hindi.

(b) Approach: This approach uses part-of-speech tagger as a pre-processing step and employs number and gender agreement and animistic knowledge features of the noun phrase in later steps.

(c) Strength and weakness: As mentioned by author, this approach cannot resolve the honorific nouns. A method called transitive anaphora resolution is also proposed.

3.12 Knowledge poor or Corpus based approaches

3.12.1 Constraint matching method

Agarwal et al. (2007) [3] presented a semantic analysis based approach of AR with a focus on texts that mainly employ simple sentences.

Table 6. *Comparative analysis of Knowledge Rich (Rule Based) AR approaches in Hindi*

Sr. No.	Author/Year	Key Idea	Data set	Performance Measurement	Accuracy
1.	Prasad and Strube (2000)	C f -list ranking method	Collection of short stories and news articles	Precison	73% to 89%
2.	[29]	Morphological markings of subject, object, clause etc.	Not mentioned	Precison	82%
3.	[39]	Choose suitable NP as antecedent by traversal of parse tree and use of syntactic information	Small stories and manually collected complex sentences.	Precison	77.5%
4.	Uppalapu and Sharma (2009)	Extract the grammatical role of anaphors and antecedents using two separate S-list	Not mentioned	Precison	Not reported
5.	Singh et al. (2014)	Gazetteer method based classification	Collection of short stories, biography and news articles	Not mentioned	Not explicitly reported
6.	[2]	Paninian based dependency structures as a source of syntactic-semantic information	User-User interaction (chat), user-system interaction and Hindi play story corpus	Precison	59% to 64%
7.	Singla and Kumar (2017)	Case based identification of preferred noun and centering algorithm for identification of pronoun and its referents.	Random set of 500 segment	Precison	81%
8.	Tewani (2020)	GNP agreement and animistic knowledge based features	Collection of short Hindi play story	Precison	81.4 to 85.7 %

(a) Primary focus: The approach was proposed for pronoun resolution having noun phrases as their antecedents in the preceding sentences. For every occcurance of a pronoun in the target sentences, it is extracted along with the nouns in the previous sentence.

(b) Approach: The constraint matching method is used to perform the resolution. For constraint matching, a database of words and their grammatical attributes (in the form of a table) was made and used. While discussing about high degree of accuracy of the algorithm, authors gave following arguments:

i) In case of simple sentences, English and Hindi both use pronouns generally as anaphoric rather than cataphoric.

ii) In case of simple sentences, the subject of a sentence is more likely to be referred by an anaphor in the successive sentence than any other noun in the sentence.

iii) In most of the simple sentences, the subject is the first noun phrase.

(c) Strength and weakness: Since Hindi is a vast language and has borne a large number of modifications with the grammar or vocabulary. Therefore, the production rules are not exhaustive to cover the entire expanse of a language like Hindi. Likewise, the database of words or the dictionary also is also limited one and demands enhancement based on the text to be analyzed.

(d) Efficiency measure: The authors claimed 96% accuracy for simple sentences. But in case of compound and complex sentences it drops down up to 80%.

3.12.2 CRF based approach

Ram and Devi (2012) presented a co-reference resolution system using Conditional Random Fields (CRF) based graphical approach and divided resolution task into pronominal and non-pronominal resolution.

(a) Primary focus: Tree CRFs and linear CRF were used for pronoun and non-pronoun resolution respectively and heuristic based approach for generation of chain.

(b) Approach: The features used in Tree CRFs are classified into three feature classes named as Node Features, Sibling and Parent Nodes based Features and Edge Clique Features. Node features indicate node's syntactic category like subject, object, and complement of PP etc. Sibling and parent node features indicate the features of an individual node with respect to the other surrounding nodes. Edge Clique Features are joint features taken over the output random variables that factor over the tree. Features used in Linear CRFs are:

i) Head noun similarity

ii) Person, number, gender

iii) Acronym

iv) Position of the words

3.12.3 Hybrid approach

(a) Primary focus: Dakwale, Mujadia and sharma (2013) [23] presented a hybrid approach to resolve Entity pronoun references in Hindi. Rather to use phrase-structure syntax as a source of syntactic information, authors have explored use of dependency structures through a rule based model and resolved simple anaphoric references.

(b) Approach: To resolve more ambiguous instances, a decision tree classifier is used with association of grammatical and semantic features. In favour of using dependency structures, authors claimed that *"dependency structures are more suitable representations for relatively free-word-order languages such as Hindi"*. The resolution system developed using this hybrid approach consists of two modules namely rule based resolution module and classifier module. The rule based module attempts to resolve the pronouns and corresponding antecedent while classifier module attempts to classify the pronoun in to various categories like reflexive, locative, relative, possessive, ergative etc. The resolution module uses the dependency relations and other information based on the category of the pronoun and classifier module uses the approach of Soon, Ng and Lim (2001) for classification.

(c) Strength and weakness: Since distal pronoun can refer to animate as well as inanimate object, ambiguity in resolving the distal pronouns, system accuracy is exceptionally low than that of proximal pronouns.

(d) Efficiency measure: In case of proximal pronoun accuracy is approximate 32% while for distal pronoun accuracy reaches upto 68%. Hence system achieved a substantial accuracy of 60%. This measure difference in accuracy for distal and proximal pronoun implies that dependency relations are much helpful in achieving an acceptable resolution performance for Hindi. Moreover, rather to apply a rule badsed system, a substantial improvement of 10% can be achieved by application of decision tree classifier.

3.12.4 Generic anaphora engine for Indian languages

(a) Primary focus: Devi, Ram and Pattabhi (2014) presented a generic anaphora engine for Indian languages. This approach uses morphological richness of Hindi and performs an in-depth morphological analysis, (both inflectional and derivational morphology) for a given word.

(b) Approach: Taking shallow parsed text as input, algorithm analyses similarities and variations between pronouns and their agreement with antecedents. Limited shallow parsing is performed on both training and testing data. Both the data are pre-processed with morphological analyser, Part-of-Speech (POS) tagger, Chunker, Clause boundary identifier and Named Entity Recognizer.

(c) Strength and weakness: To handle the variation in the antecedent-anaphor agreement an in-depth morphological analysis of the text is performed. To resolve the antecedent, algorithm used CRFs, a linear graphical machine learning, while heuristic rule based approach was used to select the candidate noun phrases for a given pronoun and machine learning techniques based approach to filter the exact antecedent noun phrase.

3.12.5 Ensemble learning based Co-Reference Resolution Model

Mentioning the importance of category of reference type in resolution strategy selection Mujadia et al. (2016b) separated out pronouns based on their reference types through pronominal reference type identifier and presented a ensemble learning based co-reference resolution modesl.

(a) Primary focus: The presented approaches was developed with focus on pronominal (abstract or concrete) and event anaphora resolution.

(b) Approach: This approach applied language specific rules and pronominal placement for pronominal type identification in sentential discourse as main features. Paninian dependency grammar and proximity of events were considered as main feature for event anaphora resolution. After that, the identification function is used to weight the out-puts of rule and ensemble identifiers. The identification function, then, assigns the resultant pronominal type category for a pronoun.

(c) Strength and weakness: First layer predicts the relations between candidate noun phrases and the target pronoun based on the contextual information learned by neural networks. The second layer is a knowledge attention module to focus on appropriate knowledge based on the given context.

(d) Efficiency measure: In case of pronominal reference type identification, accuracy achieved by the model was around 90% while for event anaphora resolution accuracy measurement was around 71%.

3.13 Deep Learning Approaches

3.13.1 Hindi NER model using MuRIL with CRF layer

Based on a hybrid deep neural network approach and incorporating MuRIL with a conditional random field (CRF) layer, sharma, Morwal and Agarwal (2022) [1] presented a Hindi NER system.

(a) Primary focus: sharma, Morwal and Agarwal (2022) [1] presented a Hindi NER system by employing MuRIL with a conditional random field (CRF) layer.

Table 7. *Comparative analysis of Knowledge Poor (Corpus Base) AR approaches in Hindi*

Sr. No.	Author/Year	Key Idea	Data set	Performance Measurement	Accuracy
1.	[3]	Semantic analysis based constraint matching	Not mentioned	Precision	80% to 96%
2.	Ram and Devi (2012)	Tree CRFs and linear CRF	Five different genres collected from CoNLL Shared Task 2011	Precision, Recall and F-Measure	46.23% to 66.66%
3.	[3]	Dependency structures through a rule based model and decision tree classifier with association of grammatical and semantic features.	Hindi and Urdu Dependency Treebank	Precision	60% to 70%
4.	[33]	Extracting the morphological feature and using shallow parsed text	Data set of tool contest ICON 2011	Precision, Recall and F-Measure	Not reported
5.	Mujadia et al. (2016)	Incorporates appropriate knowledge source as per case type of pronoun	Not mentioned	Not mentioned	90% and 71%

(b) Approach: The proposed model incorporates the recently developed MuRIL (Khanuja et al., 2021) pre-trained model especially trained for Indian languages. The architecture of the MuRIL language model is comprised of 12 encoder layers with 12 self-attention heads and 768 hidden layer dimensions. Thus, every input token to the MuRIL layer is eventually represented as a 768-dimensional dense vector.

(c) Strength and weakness: Experiment results shown that even without the use of any linguistic feature, rules, any POS information, and chunk information, system performance is superior. Another advantage of the proposed approach is that instead of just using the last layer's representation, it computes the addition of the last 4 layers representations of the MuRIL model and fine-tune the whole model.

(d) Efficiency measure : The proposed model achieved state-of-the-art results as 87.89% precision, 83.74% recall and 85.77% F1-score and outperforms all other existing Hindi NER systems developed on the ICON 2013 dataset.

3.13.2 DeepHCoref learning Model

Using the deep neural network architecture, Patiyal et al. (2022) presented the current state-of-the-art co-reference resolution system for Hindi at first time.

(a) Primary focus: The model was proposed with the aim of minimizing the need of hand-crafted features and to investigate system performance with IndicBERT and mBERT language models on same dataset.

(b) Approach: Authors employed the co-reference resolution approach proposed by Lee et al. (2018) as a major step. External Mention Detection module (Aloraini et al 2020) [5] was used for candidate mentions detection step. Bi-GRU-CNN alongwith Bi-affine classifier was utilized to get the span representation. Pre-trained Indic BERT, MuRIL and BERT were employed for the span representation purpose.

(c) Strength and weakness: In compare to Rule-based model deployed for Hindi, performance of proposed model (DeepHCoref + mBERT + HMD) is less.

(d) Efficiency measure: According to the results, the mBERT language model performs considerably better than the IndicBERT language model and MuRIL. Respective F1-score measured by mBERT, Indic BERT and MuRIL was 54.17%, 33.72% and 28.50% on joint HM model.

3.13.3 Attention Based Code Mixed Model for Social Media Text

Attempting to anaphora resolution problem associated with code-mixed text produced by linguistically diverse population using social media plateforms, Singh, Patel and Bhattacharya (2020) presented a deep learning based encoder-decoder model with attention.

(a) Primary focus: Restricted word size imposed by social media platforms sometimes induces the challenge of determining the antecedent of an anaphor without sufficient context or any background knowledge. Authors attempted to deal with such code-mixed text where antecedent determination becomes more difficult due to insufficient context availability.

(b) Approach: The encoder and decoder layers of the model have 100 GRU units and a multi-head attention layer. Adam Optimizer was used to optimise the weights and lower the loss. The model was trained with four different sets of hyperparameters by varying the loss function, learning rates, hidden units, and weight coefficients across 100 epochs using an early stopping feature. The weighted loss used in the model's development strongly penalised inaccurate predictions for non-index.

(c) Strength and weakness: Though antecedent values predicted by the model are low, but most projected labels are accurate. Due to the poor recall value F-measure also goes down and reached to 0.21. Out of 48 documents tagged by the model, 31 documents had the proper cluster indicated in the list of clusters that the model had mapped in each document. Model failed to recognise any cluster for 16 documents, making them false negative cases. In one document, the model mistakenly identified a cluster, creating a false positive instance.

(d) Efficiency measure: The result shows a precision of 0.55 and 0.42 and a recall of 0.16 and 0.14 on validation and test set respectively.

4. Research Gaps and Future Directions

4.1 Focus On Unresolved Issue

There is need to develop a better algorithm capable to handle pronouns in intrasentential, intersentential, entity and event sentences, as well as capable to deal on all issues at the same time.

4.2 Blending Of Features, Approaches And Pre-Processing Tools To Boost Up The Resolution Process

Since depending upon the language involved in resolution process there might be the differences in significance level of individual linguistic knowledge source, suitability of approach and pre-processing requirement. For example, for morphologically rich languages like Hindi, use of morphological knowledge might have higher significance while for languages like English, use of syntactic and lexical knowledge might be more important. Therefore, determining that blending of which features, approach and theory could boost up the efficiency and performance might be beneficial.

4.3 Resolution Specific Data Set And Tools

Similar to the requirement of standard evaluation measure, none of the approaches of AR conducted experiments on standard data set. So there is huge need of standard data set for Hindi. Furthermore, configuring the pre-processing tools like POS tagger etc. from anaphora resolution point of view might be beneficial.

4.4 Adopting Deep Learning Like New Approaches

The recent advances in the NLP technologies and the use of deep learning models, has resulted in a shift of anaphora resolution approaches from rule based to machine learning and further deep neural networks; use of hand-crafted features to end-to-end deep learning-based approaches. This technological advancements has shown greater promise of finding solutions for a number of NLP problems for low resource languages as well. Hence anaphora resolution for low resource languages also find prominent place in the research domain.

4.5 Need Of Standard Evaluation Measures

It can be observed quite easily that although in order to measure the performance of resolution procedure, standard and globally accepted evaluation parameters and metrics like MUC, BCUB, CEAFM, CEAFE and BLANC have been evolved, but their applications are seen mostly on languages like English only. Study of various existing anaphora resolution approaches, in particularly applied for Hindi language, exhibited that performance measure of these approaches have not been supported by any standard evaluation parameters, also not have mentioned method of measurement.

5. Conclusion

Recognizing the significance of AR for MT and other NLP applications, this paper presented a systematic and updated review of AR related work in general and approaches in particular. Unlike other survey papers published so far, this paper included only those articles or research work which were relevant to Hindi and closely related languages. This paper also presented a very first discussion on the use of linguistic knowledge sources in AR for Hindi with illustrative examples. More over, a systematic review of almost existing AR approaches for Hindi has been provided with four key aspects: primary focus, approach, strength and weakness and efficiency measure. At last, on the basis of study and analysis, some research gaps also have been listed.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1] Agarwal, C., & Dutta, K. (2021). Importance of Anaphora Resolution in Machine Translation. *Bhartiya Vaigyanik Evam Audhyogik Anusandhan Patrika*. 29(1);49-54.

[2] Agarwal, D., Mujadia, V., Mamidi, R., & Sharma, D. M. (2015). Paninian Grammar Based Hindi Dialogue Anaphora Resolution. In Proceeding of 19th International Conference on Asian Language Processing (IALP), Soochow University, China. pp. 53-56.

[3] Agarwal, S., Srivastava, M., Agarwal, P., & Sanyal, R. (2007). Anaphora Resolution in Hindi Documents. In Proceeding of 2007 International Conference on Natural Language Processing and Knowledge Engineering (IEEE NLP-KE 2007), Beijing. pp. 452-458.

[4] Ahir, P., Mehta, B., Desai, R., Patel, Z., Patel, E., & Adhvaryu, N. (2015). Anaphora Resolution for Hindi Language. *International Journal of Computer Science and Information Technologies*. 6(6);5328-5330.

[5] Aloraini, A., Yu, J., & Poesio, M. (2020). Neural Coreference Resolution for Arabic. In Proceedings of the 3rd Workshop on Computational Models of Reference, Anaphora and Coreference, Barcelona, Spain. pp. 99-110.

[6] Annam, V., Koditala, N., & Mamidi, R. (2019). Anaphora Resolution in Dialogue Systems for South Asian Languages. http://arxiv.org/abs/1911.09994

[7] Antunes, J., Lins, R. D., Lima. R., Oliveira, H., Riss, M., & Simske, S. J. (2018). Automatic Cohesive Summarization with Pronominal Anaphora Resolution. *Computer Speech and Language*. 52;141-164. https://doi.org/10.1016/j.csl.2018.05.004

[8] Athira S, Lekshmi, T. S., Rajeev, R. R., Sherly, E., & Reghuraj, P. C. (2014). Pronominal Anaphora Resolution Using Salience Score for Malayalam. In 1st IEEE International Conference on Computational Systems and Communications (ICCSC), Trivandrum, India. pp. 47-51. doi: 10.1109/COMPSC.2014.7032619

[9] Atkinsona, J., & Escudero, A. (2022). Evolutionary Natural Language Co-reference Resolution for Sentiment Analysis. *International Journal of Information Management Data Insights*. 2(2);100-115.

[10] Begum, R., Husain, S., Dhwaj, A., Sharma, D M., Lakshmi Bai, & Sangal, R. (2008). Dependency Annotation Scheme for Indian Languages. In Proceeding of 3rd International Joint Conference on Natural Language Processing (IJNLP 2008), Hyderabad, India. pp. 721-726.

[11] Bharati, A., Bhargava, Y K., & Sangal, R. (1993). Reference and Ellipsis in an Indian Languages Interface to Database. *Computer Science and Informatics*. 23(3).

[12] Bharati, A., Husain, S., Sharma, D M., & Sangal, R. (2008). A Two-Stage Constraint Based Dependency Parser for Free Word Order Languages. In Proceedings of the COLIPS International Conference on Asian Language Processing (IALP), Chiang Mai, Thailand.

[13] Bharati, A., Husain, S., Sharma, D M., Begum, R., & Sangal, R. (2009). AnnCorra: Tree Banks for Indian Languages, Guidelines for Annotating Hindi Treebank. Technical Report (version – 2.0), Language Technologies Research Centre, IIIT Hyderabad.

[14] Bhargav, U., & Sharma, D M. (2009). Pronoun Resolution for Hindi. In Proceeding of 7th Discourse Anaphora and Anaphor Resolution Colloquium (DAARC 2009), Goa, India.

[15] Bhattacharjee, S., Haque, R., de Buy Wenniger, G. M., & Way, A. (2020). Investigating Query Expansion and Coreference Resolution in Question Answering on BERT. In International Conference on Applications of Natural Language to Information Systems (NLDB 2020). 12089;47-59. https://doi.org/10.1007/978-3-030-51310-8_5

[16] Botley, S. P. (2006). Indirect Anaphora: Testing the Limits of Corpus Based Linguistics. *International Journal of Corpus Linguistics*. 11(1);73-112.

[17] Chandra Mohan, D., & Sadanandam, M. (2014). Telugu Pronominal Anaphora Resolution. *International Journal of Research and Applications*. 1(1);23-30.

[18] Chatterji, S., Dhar, A., Barik, B., Moumita, P. K., Sarkar, S., & Basu, A. (2011). Anaphora Resolution for Bengali, Hindi and Tamil Using Random Tree Algorithm in Weka. In Proceedings of 9th International Conference on Natural Language Processing (ICON 2011), Anna University, Chennai, India. pp. 7-12. http://ltrc.iiit.ac.in/icon2011/contests.html

[19] Cormier, K., Schembri, A., & Woll, B. (2013). Pronouns and Pointing in Sign Languages. *Lingua*. 137;230-247. https://doi.org/10.1016/j.lingua.2013.09.010

[20] Cornish, F. (2001). Modal That as Determiner and Pronoun: The Primacy of The Cognitive Interactive Dimension. *English Language and Linguistics*. 5(2);297-315. doi:10.1017/S1360674301000259

[21] Cysouw, M. (2001). The Paradigmatic Structure of Person Marking. Unpublished Doctoral Dissertation, Radboud University, Nijmegen, Netherlands.

[22] Dakwale, P., Sharma, H., & Sharma, D M. (2012). Anaphora Annotation in Hindi Dependency Tree Bank. In Proceedings of the 26th Pacific Asia Conference on Language, Information and Computation (PACLIC), Bali, Indonesia. pp. 391-400.

[23] Dakwale, P., Mujadia, V., & Sharma, D. M. (2013). A Hybrid Approach for Anaphora Resolution in Hindi. In Proceedings of the 6th International Joint Conference on NLP, Nagoya, Japan. pp. 977-981.

[24] Dalal, A., Nagaraj, K., Sawant, U., & Shelke, S. (2006). Hindi Part-of-Speech Tagging and Chunking: A Maximum Entropy Approach. In Proceeding of the NLPAI Machine Learning Competition.

[25] Davison, A. (2000). Lexical anaphors in Hindi/Urdu. In: K. Wali, K.V. Subbarao, B. Lust and J. Gair (eds.) Lexical Anaphors and Pronouns in Some South Asian languages: A Principled Typology. *Mouton de Gruyter*. pp. 397-470.

[26] Davison, A. (2001). The VP Structure and Case Checking Properties of Sentences with Non-nominative Subjects: Hindi/Urdu. University of Iowa.

[27] Desai, N. P., & Dabhi, V. K. (2021). Taxonomic Survey of Resources for Hindi Language NLP Systems. ArXiv, abs/2102.00214.

[28] Desai, N. P., & Dabhi, V. K. (2022). Resources and Components for Gujarati NLP Systems: A Survey. *Artificial Intelligence Review*. 55(7);1-19. https://doi.org/10.1007/s10462-021-10120-1

[29] Devi, S L., & Patnaik, B. N. (2002). Vasisth: An Anaphora Resolution System for Malayalam and Hindi. In Symposium on Translation Support Systems, IIT Kanpur.

[30] Devi, S L., Pattabhi R. K. Rao, Ram, V. S., Malarkodi, C. S., & Akilandeswari, A. (2011). Hybrid Approach for Co-Reference Resolution. In Proceedings of the 15th Conference on Computational Natural Language Learning: Shared Task, Portland, Oregon, USA. pp. 93-96.

[31] Devi, S. L. (2008). Anaphora Resolution Using Named Entity and Ontology. In Proceedings of 2nd Workshop on Anaphora Resolution (WAR II), NEALT Proceedings Series by Christer Johansson, Bergen, Norway. 2;91-96.

[32] Devi, S. L., & Patnaik, B. N. (2000). Vasisth: An Anaphora Resolution System for Malayalam and Hindi. In Proceedings of International Conference on Artificial and Computational Intelligence for Decision, Control and Automation In Engineering and Industrial Applications. Monastir, Tunisia.

[33] Devi, S. L., Ram, V. S., & Pattabhi, R. K. (2014). A Generic Anaphora Resolution Engine for Indian Languages. In proceeding of 25th International Conference on Computational Linguistics (COLING 2014), Dublin, Ireland. pp. 1824-1833.

[34] Devi, S.L. (2020). Anaphora Resolution from Social Media Text in Indian languages (SocAnaRes-IL) Overview. In Proceedings of the 12th Annual Meeting of the Forum for Information Retrieval Evaluation (FIRE Dec 2020). pp. 9-13. https://doi.org/10.1145/3441501.3441512

[35] Dhar, A., & Garain, U. (2008). A Method for Pronominal Anaphora Resolution in Bengali. In Proceedings of the 6th International Conference on Natural Language Processing (ICON), India.

[36] Dorr, B. J. (1994). Classification of Machine Translation Divergences and a Proposed Solution. *Computational Linguistics*. 20(4);597-633.

[37] Dutta K., Prakash, N., & Kaushik, S. (2009). Application of Pronominal Divergence and Anaphora Resolution in English-Hindi Machine Translation. *POLIBITS, Computer Science and Computer Engineering with Applications*. 39;55-58.

[38] Dutta, K., Kaushik, S., & Prakash, N. (2011). Machine Learning Approach for the Classification of Demonstrative Pronouns for Indirect Anaphora in Hindi News Items. *The Prague Bulletin of Mathematical Linguistics*. 95;33-50.

[39] Dutta, K., Prakash, N., & Kaushik, S. (2008). Resolving Pronominal Anaphora in Hindi Using Hobbs' Algorithm. *Web Journal of Formal Computation and Cognitive Linguistics*.

[40] Dutta, K., Prakash, N., & Kaushik, S. (2010). Probabilistic Neural Network Approach to the Classification of Demonstrative Pronouns for Indirect Anaphora in Hindi. *International Journal of Expert Systems with Applications*. 37(8);5607-5613.

[41] Evans, N., & Levinson, S. C. (2009). The Myth of Language Universals: Language Diversity and Its Importance for Cognitive Science. *Behavioral and Brain Sciences*. 32(5);429-448. doi:10.1017/S0140525X0999094X

[42] Gopal, M., & Jha, G. N. (2014). Resolving Anaphors in Sanskrit. In: Vetulani, Z., Mariani, J. (eds) Human Language Technology Challenges for Computer Science and Linguistics. LTC 2011. Lecture Notes in Computer Science(), vol 8387. *Springer, Cham*. pp. 83-92. https://doi.org/10.1007/978-3-319-08958-4_7

[43] Grosz, J. B., Joshi, A . K., & Weinstein, S. (1995). Centering: A Framework for Modelling the Local Coherence of Discourse. IRCS Technical Report Series, University of Pennsylvania. 21(2);203-225.

[44] Gundel, J. K., Hedberg, N., & Zacharski, R. (2012). Underspecification of Cognitive Status in Reference Production: Some Empirical Predictions. *Topics in Cognitive Science*. 4(2);249-268. https://doi.org/10.1111/j.1756-8765.2012.01184.x

[45] Gundel, J. K., Hedberg, N., & Zacharski, R. (1993). Cognitive Status and the Form of Referring Expressions in Discourse. *Language*. 69(2);274-307.

[46] Gundel, J. K., Bassene, M., Gordon, B., Humnick, L., & Khalfaoui, A. (2007). Reference and Cognitive Status: Results from Corpus Studies of Eegimaa, Kumyk, Ojibwe, and Tunisian Arabic. In 10th International Pragmatics Conference, Göteborg, Sweden.

[47] Gupta, D., & Chatterjee, N. (2001). Study of Divergence for Example Based English-Hindi Machine Translation. (STRANS-2001), IIT Kanpur. pp. 43-51.

[48] Gupta, D., & Chatterjee, N. (2003). Identification of Divergence for English to Hindi EBMT. In Proceedings of 3rd MT Summit. pp. 141-148.

[49] Halliday, M. K., & Hasan, R. (1976). Cohesion in English. *Longman English Language Series*; No. 09, London.

[50] Hirst, Graeme John. (1979). Technical report 79-2, Department of Computer Science, University of British Columbia, Vancouver, Canada.

[51] Hirst, G. J. (1981a). Anaphora in Natural Language Understanding: A Survey. Lecture notes in computer science, *Springer-Verlag*.

[52] Hirst, G. J. (1981b). Discourse-Oriented Anaphora Resolution in Natural Language Understanding: A Review. *American Journal of Computational Linguistics*. 7(2);85-98.

[53] Hobbs, J. R., (1976). Pronoun Resolution. A Research Report in Department of Computer Science, City College, City University of New York.

[54] Huang, Y. (2000). Anaphora: A Cross-Linguistic Approach. *Oxford University Press*. ISBN: 0198235283.

[55] Huang, Y. (2000). Discourse Anaphora: Four Theoretical Models. *Journal of Pragmatics*. 32(2);151-176. https://doi.org/10.1016/S0378-2166(99)00041-7

[56] Hou, Y. (2020). Bridging Anaphora Resolution as Question Answering. https://doi.org/10.48550/arXiv.2004.07898

[57] Jain P., Mittal, M., Mukerjee, A., & Raina, A. M. (2004). Anaphora Resolution in Multi-Person Dialogue. In Proceedings of the 5th SIGdial Workshop on Discourse and Dialogue, Association for Computational Linguistics, Boston, Cambridge, Massachusetts.

[58] Jain, S., Jain, N., Tammewar, A., Bhat, R A., & Sharma, D M. (2013). Exploring Semantic

Information in Hindi WordNet for Hindi Dependency Parsing. In Proceedings of the 6th International Joint Conference on Natural Language Processing (IJCNLP), Nagoya, Japan. pp. 189-197.

[59] Jena, I., Bhat, R A., Jain, S., & Sharma D M. (2013). Animacy Annotation in the Hindi Treebank. In Proceedings of the 7th Linguistic Annotation Workshop and Interoperability with Discourse, Sofia, Bulgaria. pp. 159-167.

[60] Jha, G. N., Devi, S. L., Mishra, D., Singh, S. K., & Pralayankar, P. (2008). Anaphora in Sanskrit. In Proceedings of 2nd Workshop on Anaphora Resolution (WAR II), NEALT Proceedings Series by Christer Johansson, Bergen, Norway. 2;11-25.

[61] Jha, G. N., Gopal, M., & Mishra, D. (2011). Annotating Sanskrit Corpus: Adapting IL-POSTS. In: Vetulani, Z. (eds) Human Language Technology. Challenges for Computer Science and Linguistics. LTC 2009. Lecture Notes in Computer Science(), vol 6562. *Springer, Berlin, Heidelberg*. pp. 371-379. https://doi.org/10.1007/978-3-642-20095-3_34

[62] Jonnalagadda, H. R., & Mamidi, R. (2015). Resolution of Pronominal Anaphora for Telugu Dialogues. In Proceedings of the 12th International Conference on Natural Language Processing.

[63] Kameyama, M. (1997). Intra-sentential centering: A case study. CoRR, cmp-lg/9707005.

[64] Kaur, H., & Kaur, K. (2016). A Survey of Anaphora Resolution Approaches for Indian Languages. *International Journal of Engineering Research in Computer Science and Engineering*. 3(6);111-115.

[65] Kaur, K., Goyal, V., & Dutta, K. (2020). Design and Implementation of Anaphora Resolution in Punjabi Language. In Proceedings of the 17th International Conference on Natural Language Processing (ICON): Patna, India. pp. 35-36.

[66] Kaur, K., Goyal, V., & Dutta, K. (2021). Machine Learning Approach for Resolving Anaphors in the Punjabi Language. In Proceedings of 1st International Conference in Information and Computing Research (iCORE). pp. 50-55. https://doi.org/10.1109/iCORE54267.2021.00028

[67] Kaur, K., Goyal, V., & Dutta, K. (2022). Corpus Creation for Anaphora Resolution in Punjabi Language. In: Singh, P.K., Singh, Y., Kolekar, M.H., Kar, A.K., Gonçalves, P.J.S. (eds) Recent Innovations in Computing. Lecture Notes in Electrical Engineering *Springer, Singapore*. 832;17-31.

[68] Khandale, K. B., & Mahender, C. Namrata. (2019). Rule-based Design for Anaphora Resolution of Marathi Sentence. In Proceedings of 5th IEEE International Conference for Convergence in Technology (I2CT). pp. 1-7.

[69] Khandale, K. B., & Mahender, C. Namrata. (2021). Issues and Framework of Rules for Resolving Anaphora in Marathi Text. In Proceedings of International Conference on Data Science and Applications. pp. 93-107.

[70] Khandale, K. B., & Mahender, C. Namrata. (2021). Resolving Anaphora Using Gender and Number Agreement in Marathi Text. In Proceedings of the International Conference on Data Science, Machine Learning and Artificial Intelligence (DSMLAI 21). pp. 116-123.

[71] Khanuja, S., Bansal, D., Mehtani, S., Khosla, S., Dey, A., & Gopalan, B. et al. (2021). Muril: Multilingual representations for indian languages. arXiv preprint arXiv:2103.10730.

[72] Kilicoglu, H., Rosemblat, G., Fiszman, M., & Rindflesch, T. C. (2016). Sortal Anaphora Resolution to Enhance Relation Extraction from Biomedical Literature. *BMC Bioinformatics*. 17(1);163. https://doi.org/10.1186/s12859-016-1009-6

[73] Khullar, P. (2021). Why Find the Right One? In Proceedings of the 16th Conference of the European Chapter of the Association for Computational Linguistics (EACL April 2021): Student Research Workshop. pp. 203-208. doi:10.18653/v1/2021.eacl-srw.26

[74] Kimmelman, V. (2009). Reflexive Pronouns in Russian Sign Language and Sign Language of The Netherlands. MA Thesis, University of Amsterdam.

[75] Kohen, P. (2010). Statistical Machine Translation. *Cambridge University Press*.

[76] Kukkar, A., & Mohana, R. (2016a). Anaphora Resolution in Hindi: Issues and Directions. *Indian Journal of Science and Technology*. 9(32).

[77] Kukkar, A., & Mohana, R. (2016b). Improving Anaphora Resolution by Resolving Gender and Number Agreement in Hindi Language Using Rule Based Approach. *Indian Journal of Science and Technology*. 9(32);1-5.

[78] Kukkar, A., kaur, S., & Mohana, R. (2016c). Anaphora Resolution in Hindi: A Hybrid Approach. The International Symposium on Intelligent Systems Technologies and Applications (ISISTA). pp. 815-830.

[79] Lahoti, P., Mittal N., & Singh, G. (2022). A Survey on NLP Resources, Tools, and Techniques for Marathi Language Processing. *ACM Transactions on Asian and Low-Resource Language Information Processing*. 22(2);1-34. https://doi.org/10.1145/3548457

[80] Lakhmani, P., & Singh, S. (2013). Anaphora Resolution in Hindi Language. *International Journal of Information and Computation Technology*. 3(7);609-616.

[81] Lakhmani, P., Singh, S., & Mathur, P. (2014a). Gazetteer Method for Resolving Pronominal Anaphora in Hindi Language. *International Journal of Advances in Computer Science and Technology*. 3(3);173-176.

[82] Lakhmani, P., Singh, S., & Morwal, S. (2014b). Performance Analysis of two Anaphora Resolution System for Hindi Language. *International Journal of Computer Science and Mobile Computing*. 3(3);576-580.

[83] Lappin, S., & Hueh, T. (1994). A Generalized Reconstruction Algorithm for Ellipsis Resolution. In Proceeding of 16th International Conference on Computational Linguistics (COLING 1996). Vol 2;535-561.

[84] Lata, K., Singh P., & Dutta K. (2022). Mention Detection in Coreference Resolution: Survey.

Applied Intelligence. 52;9816-9860. https://doi.org/10.1007/s10489-021-02878-2

[85] Lata, K., Singh, P., & Dutta, K. (2022). DeepHCoref: A Deep Neural Coreference Resolution for Hindi Text. Research Square. https://doi.org/10.21203/rs.3.rs-2088505/v1

[86] Lata, K., Singh, P., & Dutta, K. (2021). A Comprehensive Review on Feature Set Used for Anaphora Resolution. *Artificial Intelligence Review*. 54(4);2917-3006. https://doi.org/10.1007/s10462-020-09917-3

[87] Petitto, L. A. (1987). On The Autonomy of Language and Gesture: Evidence From the Acquisition of Personal Pronouns in American Sign Language. *Cognition*. 27(10);1-52. https://doi.org/10.1016/0010-0277(87)90034-5

[88] Lee, K., He, L., & Zettlemoyer, L. (2018). Higher-Order Coreference Resolution with Coarse-to-Fine Inference. In Proceedings of the 2018 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 2. pp. 687-692.

[89] Levinson S. C. (2000). Presumptive Meanings: The Theory of Generalized Conversational Implicature. *MIT Press*. ISBN electronic: 9780262278256. https://doi.org/10.7551/mitpress/5526.001.0001

[90] Loaiciga, S., & Wehrli, E. (2015). Rule-Based Pronominal Anaphora Treatment for Machine Translation. In Proceedings of the 2nd Workshop on Discourse in Machine Translation. pp. 86-93.

[91] Humnick, L. A. (2009). Pronouns in Kumyk Discourse: A Cognitive Perspective. PhD Thesis, The University of Minnesota.

[92] Mahato, S., & Thomas, A. (2015a). Exploring Semantic Information from Hindi Dependency Treebank for Resolving Pronominal Anaphora. In IJCA Proceeding on National Conference on Knowledge, Innovation in Technology and Engineering (NCKITE 2015). pp. 27-34.

[93] Mahato, S., & Thomas, A. (2015b). Machine Learning Approach for Resolving Pronominal Anaphora Using Hindi Dependency Treebank. *International Journal of Advanced Engineering Research and Studies*. 4(2);155-159.

[94] Mahato, S., Thomas, A., & Sahu, N. (2017). A Relative Study of Factors and Approaches for Hindi Anaphora Resolution. *International Journal of Management, IT & Engineering*. 7(12);176-188.

[95] Mahato, S., Thomas, A., & Sahu, N. (2018). A Survey on Anaphora Resolution Toolkits. *International Journal for Research in Applied Science & Engineering Technology*. 5(12);796-801.

[96] Mahato, S., Thomas, A., & Sahu, N. (2020). Heuristic Algorithm for Resolving Pronominal Anaphora in Hindi Dialect. Advanced Computing and Intelligent Engineering. Advances in Intelligent Systems and Computing, *Springer, Singapore*. 1082;41-51.

[97] Maleki, M., & Tabrizi, H H. (2017). A Corpus-based Study of Human-Translated vs. Machine-translated Texts: The Case of Ellipsis in English-Persian Translation. *Journal of Applied Linguistics and Language Research*. 4(1);290-303.

[98] Poesio, M. (2016). Linguistic and Cognitive Evidence About Anaphora. In: Poesio, M., Stuckardt, R., Versley, Y. (eds) Anaphora Resolution. Theory and Applications of Natural Language Processing. *Springer, Berlin, Heidelberg*. https://doi.org/10.1007/978-3-662-47909-4_2

[99] Mehla, K., & Jangra, A. (2015). Event Anaphora Resolution in Natural Language Processing for Hindi text. *International Journal of Innovative Science, Engineering & Technology*. 2(1);620-623.

[100] Michael, A., Hedderich, L. L., Heike, A., Jannik, S., & Dietrich, K. (2021). A Survey on Recent Approaches for Natural Language Processing in Low-Resource Scenarios. In Proceedings of the 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies. pp. 2545-2568.

[101] Mitkov, R., Choi, S. K., & Sharp, R. (1995). Anaphora Resolution in Machine Translation. In proceedings of the 6th International Conference on Theoretical and Methodological Issues in Machine Translation (TMI' 1995), Leuven, Belgium. pp. 87-95.

[102] Mitkov, R., Evans, R., Orasan, C., Ha, L., & Pekar, V. (2007). Anaphora Resolution: To What Extent Does It Help NLP Applications? In 6th Discourse Anaphora and Anaphor Resolution Colloquium, (DAARC 2007), Lagos, Portugal. pp. 179-190.

[103] Mitkov, R. (1999a). Anaphora resolution: The state of the art. School of Languages and European Studies, University of Wolverhampton. pp. 1-34.

[104] Mitkov, R. (1999b). Introduction: Special Issue on Anaphora Resolution in Machine Translation and Multilingual NLP. *Machine Translation*. 14(3-4);159-161.

[105] Mohammadi, H. H., Talebpour, A., Aznaveh, A. M., & Yazdani, S. (2022). Review of Co-reference Resolution in English and Persian. arXiv preprint arXiv:2211.04428.

[106] Moratanch, N., & Chitrakala, S. (2023). Anaphora Resolved Abstractive Text Summarization (AR-ATS) System. *Multimedia Tools and Applications*. 82;1-29. https://doi.org/10.1007/s11042-022-13299-9

[107] Mujadia, V., Gupta, P., & Sharma, D. M. (2016a). Coreference Annotation Scheme and Relation Types for Hindi. In Proceedings of the 10th International Conference on Language Resources and Evaluation (LREC'16). pp. 161-168.

[108] Mujadia, V., Gupta, P., & Sharma, D. M. (2016b). Pronominal Reference Type Identification and Event Anaphora Resolution for Hindi. *International Journal of Computational Linguistics and Applications*. 7;245-263.

[109] Nayan, A., Rao, B. R. K., Singh, P. D., Sanyal, S., & Sanyal, R. (2008). Named Entity Recognition for Indian Languages. In Proceedings of International Joint Conference on Natural Language Processing (IJCNLP-08).

[110] Stylianou, N., & Vlahavas, I. (2021). A Neural Entity Co-reference Resolution Review. *Expert*

Systems with Applications. 168. https://doi.org/10.1016/j.eswa.2020.114466

[111] Nithya, R. (2019). Need for Anaphoric Resolution towards Sentiment Analysis-A Case Study with Scarlet Pimpernel. *International Journal of Education and Management Engineering*. 1;37-50. doi: 10.5815/ijeme.2019.01.04

[112] Pal, T. L., Dutta K., & Singh P. (2012). Anaphora Resolution in Hindi: Issues and Challenges. *International Journal of Computer Applications*. 42(18);7-13.

[113] Pareed, A., & Idicula, S. M. (2019). An Integrated Framework for Pronominal Anaphora Resolution in Malayalam. *Linguistics Advances in Science, Technology and Engineering Systems Journal*.

[114] Phadke, M., & Devane, S. (2019). Pronoun Resolution Task for Multilingual Machine Translation. In proceeding of 5th International Conference on Next Generation Computing Technologies (NGCT-2019), University of Petroleum and Energy Studies, Dehradun, India.

[115] Petitto, L. A. (1987). On The Autonomy of Language and Gesture: Evidence From the Acquisition of Personal Pronouns in American Sign Language. *Cognition*. 27(10);1-52. https://doi.org/10.1016/0010-0277(87)90034-5

[116] Poesio, M., Ponzetto, S. P., & Versley, Y. (2010). Computational Models of Anaphora Resolution: A Survey.

[117] Pralayankar, P., & Devi, S L. (2010). Anaphora Resolution Algorithm for Sanskrit. In Proceedings of International Sanskrit Computational Linguistics Symposium (ISCLS), New Delhi, India. pp. 209-217.

[118] Prasad, R. (2003). Constraints on the Generation of Referring Expressions: with Special Reference to Hindi. Ph.D. thesis, University of Pennsylvania.

[119] Prasad, R., & Strube, M. (2000). Discourse Salience and Pronoun Resolution in Hindi. In A. Williams and E. Kaiser Edition, Penn Working Papers in Linguistics. 6(3);189-208.

[120] Ram, V. S., & Devi, S. L. (2012). Co-Reference Resolution Using Tree-CRF. In Proceeding of the 13th International Conference on Computational Linguistics and Intelligent Text Processing (CICLing 2012). New Delhi, India. 1;285-296.

[121] Rajpurkar, P., Zhang, J., Lopyrev, K., & Liang, P. (2016). SQuAD: 100,000+ Questions for Machine Comprehension of Text. *Proceedings of the 2016 Conference on Empirical Methods in Natural Language Processing*, 2383-2392.

[122] Rij, J. V., Rijn, H. V., & Hendriks, P. (2010). Cognitive Architectures and Language Acquisition: A Case Study in Pronoun Comprehension. *Journal of Child Language*. 37(3), 731-766. https://doi.org/10.1017/S0305000909990560

[123] Rudnev, P. (2009). *Syntax, Semantics and Pragmatics of Aanaphor Binding in a Free Word Order Language*. *Russian State Humanities University.*

[124] Sukthanker, R., Poria, S., Cambria, E., & Thirunavukarasu R. (2020). Anaphora and Co-reference resolution: A Review. *Information Fusion.* 59, 139-162.

[125] Saha, B. N., Senapati, A., & Garain, U. (2022). A Deep Learning Framework for Anaphora Resolution from Social Media Text. In D. Gupta, K. Sambyo, M. Prasad, & S. Agarwal (Eds.), *Advanced Machine Intelligence and Signal Processing. Lecture Notes in Electrical Engineering* (Vol. 858, pp. 687-695). *Springer*. https://doi.org/10.1007/978-981-19-0840-8_53

[126] Saha, S., Ekbal, A., Uryupina, O., & Poesio, M. (2011). Single and Multi-Objective Optimization for Feature Selection in Anaphora Resolution. *Proceedings of 5th International Joint Conference on Natural Language Processing (IJCNLP)*, 93-101.

[127] Saqia, B., Khan, K., Khan, A., Khan, W., Subhan, F., & Muhammad, A. (2018). Impact of Anaphora Resolution on Opinion Target Identification. *International Journal of Advanced Computer Science and Applications.* 9(6).

[128] Mahato, S., & Thomas, A. (2020). REAH: Resolution Engine for Anaphora in Hindi dialogue. In G. R. Sinha & J. S. Suri (Eds.), *Cognitive Informatics, Computer Modelling, and Cognitive Science* (pp. 211-231). *Academic Press.* https://doi.org/10.1016/B978-0-12-819445-4.00011-4

[129] Senapati, A. (2017). *Pronominal Anaphora Resolution in Bengali* [Doctoral dissertation]. *Indian Statistical Institute.*

[130] Shapiro, M. C. (2003). Lexical Anaphors and Pronouns in Selected South Asian Languages: A Principled Typology. *The Journal of the American Oriental Society.* 123(1), 258-264.

[131] Sharma, R., Morwal, S., & Agarwal, B. (2022). Named Entity Recognition Using Neural Language Model and CRF for Hindi Language. *Computer Speech & Language*. 74.

[132] Shekhar, S., & Kumar, U. (2018). Review on the Techniques of Anaphora Resolution. *International Journal of Latest Trends in Engineering and Technology.* 8(2), 37-40.

[133] Ranjan, S., Rajkumar, R., & Agarwal, S. (2022). Locality and expectation effects in Hindi preverbal constituent ordering. *Cognition.* 223, 104959.

[134] Sikdar, U. K., Ekbal, A., & Saha, S. (2016). A Generalized Framework for Anaphora Resolution in Indian Languages. *Knowledge-Based Systems.* 109(1), 147-159.

[135] Sikdar, U., Ekbal, A., Saha, S., Uryupina, O., & Poesio, M. (2013). Adapting a State-of-the-art Anaphora Resolution System for Resource-poor Language. *Proceedings of the 6th International Joint Conference on Natural Language Processing (IJCNLP)*, 815-821.

[136] Singh, H. (2015). Resolution of Anaphors in Punjabi. *Indian Journal of Science and Technology.* 8(27), 1-4. DOI:10.17485/ijst/2015/v8i27/83320

[137] Singh, P., & Dutta, K. (2014a). Analysis and Comparison of Antecedent Type of Demonstrative

Pronoun in Context of Co-Reference Resolution: A Corpus Based Study of Hindi for Monologue and Dialogue. *Proceeding of 6th International Conference on Computational Intelligence and Communication Networks (CICN 2014)*, 536-540.

[138] Singh, P., & Dutta, K. (2014b). Annotating Indirect Anaphora for Hindi: A Corpus Based Study. *Proceeding of 6th International Conference on Computational Intelligence and Communication Networks (CICN 2014)*, 525-529.

[139] Singh, P., & Dutta, K. (2014c). Sentence Structure for Free Word Order Languages in Context with Anaphora Resolution: A Case Study of Hindi. *Proceedings of International Conference on Computer Design Engineering and Technology (ICCDET 2014).* 8(6), 2011-2014.

[140] Singh, P., & Dutta, K. (2014d). Semi-automatic Annotation scheme for Demonstrative Pronoun Considering Indirect Anaphora for Hindi. *Proceedings of 2014 International Conference on Advances in Computing, Communications and Informatics (ICACCI)*, 1710-1714.

[141] Singh, P., & Dutta, K. (2015a). Automation and Validation of Annotation for Hindi Anaphora Resolution. *International Journal of Advanced Computer Science and Applications.* 6(10), 179-185.

[142] Singh, P., & Dutta, K. (2015b). Sensitivity Analysis of Feature Set Employed for Anaphora Resolution. *International Journal of Computer Applications.* 128(14), 10-14.

[143] Singh, S., Lakhmani, P., Mathur, P., & Morwal, S. (2014a). Anaphora Resolution in Hindi Language Using Gazetteer Method. *International Journal on Computational Sciences and Applications.* 4(3), 71-76.

[144] Singh, S., Lakhmani, P., Mathur, P., & Morwal, S. (2014). Comparative Performance Analysis of Two Anaphora Resolution Systems. *International Journal in Foundations of Computer Science & Technology.* 4(2), 11-19.

[145] Singh, S., Patel, K., & Bhattacharyya, P. (2020). Attention Based Anaphora Resolution for Code-Mixed Social Media Text for Hindi Language. *Forum for Information Retrieval Evaluation (FIRE 2020).* 2826.

[146] Singh, V., & Joshi, N. (2019). A Rule Based Approach for Anaphora Resolution. *International Journal of Innovative Technology and Exploring Engineering.* 8(7), 2652-2657.

[147] Singla, D., & Kumar, P. (2017). Rule Based Anaphora Resolution in Hindi. *Proceeding of International Conference on Computational Intelligence in Data Science (ICCIDS 2017)*, 1-5.

[148] Sinha, R. M., & Thakur, A. (2005a). Divergence Patterns in Machine Translation between Hindi and English. *Proceeding of 10th Machine Translation Summit (MTS 2005)*, 346-353.

[149] Sinha, R. M., & Thakur, A. (2005b). Translation Divergence in English-Hindi MT. *Proceeding of 10th European Association for Machine Translation Summit (EAMT 2005)*, 245-254.

[150] Sinha, S. (2002). *A Corpus-based Account of Anaphor Resolution in Hindi* [Master's thesis]. *University of Lancaster.*

[151] Soon, W. M., Ng, H. T., & Lim, D. C. (2001). A Machine Learning Approach to Co-Reference Resolution of Noun Phrases. *Computational Linguistics.* 27(4), 521-544.

[152] Stojanovski, D., & Fraser, A. (2019). Improving Anaphora Resolution in Neural Machine Translation Using Curriculum Learning. *Proceedings of Machine Translation Summit XVII Vol 1: Research Track*, 140-150.

[153] Steinberger, J., Mijail, A. K., Poesio, M., & Sanchez-Graillet, O. Improving LSA-based Summarization with Anaphora Resolution.

[154] Steinbergera, S., Poesio, M., Mijail, A. K., & KarelJežeka. (2007). Two uses of Anaphora Resolution in Summarization. *Information Processing & Management.* 43(6), 1663-1680.

[155] Sukthanker, R., Poria, S., Cambria, E., & Thirunavukarasu, R. (2018). Anaphora and Coreference Resolution: A Review. *Artificial Intelligence Review.*

[156] Tewani, K. (2020). Pronominal Anaphora Resolution in Hindi Language Using Number Agreement and Animistic Knowledge. *Proceeding of 2nd International Conference on Communication, Devices and Computing (ICCDC 2019)*, 713-722.

[157] Ting, M., Kadir, R. A., Azman, A., Sembok, T. M. T., & Ahmad, F. (2019). Named Entity Enrichment Based on Subject-Object Anaphora Resolution. *Intelligent Computing-Proceedings of the Computing Conference*, 873-884. https://doi.org/10.1007/978-3-030-22868-2_60

[158] Falke, T., Meyer, C. M., & Gurevych, I. (2017). Concept-Map-Based Multi-Document Summarization using Concept Coreference Resolution and Global Importance Optimization. *Proceedings of the Eighth International Joint Conference on Natural Language Processing (Volume 1: Long Papers)*, 801-811.

[159] Trevor, J. (2013). Formational and Functional Characteristics of Pointing Signs in a Corpus of Auslan (Australian sign language): Are The Data Sufficient to Posit a Grammatical Class of Pronouns in Auslan? *Corpus Linguistics and Linguistic Theory.* 9(1), 109-159. https://doi.org/10.1515/cllt-2013-0012

[160] Vergoossen, H. P. (2021). *Breaking the Binary: Attitudes Towards the Cognitive Effects of Gender-Neutral Pronouns* [Doctoral dissertation]. *Stockholm University.* DOI:10.13140/RG.2.2.20488.14081

[161] Vicedo, J. L., & Ferrández, A. (2000). Importance of pronominal anaphora resolution in question answering systems. *Proceedings of the 38th Annual Meeting on Association for Computational Linguistics*, 555-562.

[162] Voita, E., Serdyukov, P., Sennrich, R., & Titov, I. (2018). Context-Aware Neural Machine Translation Learns Anaphora Resolution. *Proceedings of the 56th Annual Meeting of the Association for Computational Linguistics (ACL).* 1, 1264-1274. https://doi.org/10.18653/v1/P18-1117

[163] Wang, N., Yuan, C., Wong, K. F., & Li, W. (2002). Anaphora Resolution in Chinese Financial News for Information Extraction. *Proceedings of the 4th World Congress on Intelligent Control and Automation.* 3, 2422-2426.

[164] Weiner, J. S. (2014). *Pronominal Anaphora in Machine Translation* [Master's thesis]. *Karlsruhe Institute of Technology.*

[165] Wohiduzzaman, K., & Ismail, S. (2018). Recommendation System for Bangla News Article with Anaphora Resolution. *4th International Conference on Electrical Engineering and Information & Communication Technology (ICEEiCT)*, 467-472. https://doi.org/10.1109/CEEICT.2018.8628075

[166] Xue, Z., Li, R., Dai, Q., & Jiang, Z. (2022). CorefDRE: Document-Level Relation Extraction with Co-reference Resolution. https://doi.org/10.48550/arXiv.2202.10744

[167] Yu, X., Zhang, H., Hong, R., Song, Y., & Zhang, C. VD-PCR: Improving Visual Dialog With Pronoun Coreference Resolution. *Pattern Recognition.*

[168] Yadav, D. S., Dutta, K., Singh, P., & Chandel, P. (2016). Anaphora Resolution for Indian Languages: The State of the Art. *CPUH-Research Journal.* 1(2), 1-7.