An Introduction to Anaphora Resolution

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Outline

- Terminology
- Types of Anaphora
- Types of Antecedent
- Anaphora Resolution and the Knowledge Required
- Automatic Anaphora Resolution
- Theories and Formalisms
- Existing Approaches
- Issues in Continuing Research

Terminology

- Cohesion
- Anaphors
- Antecedent
- Referent
- Coreferential
- Coreferential Chain

Cohesion

- A linguistic phenomenon
- Occurs where the interpretation of some elements in the discourse is dependent on that of another
- *E.g.,* *Elizabeth* looked archly, and turned away. *Her* resistance had not injured her with the gentleman

  (-Jane Austen's *Pride&Prejudice*)
- The second sentence is related to the first one;
- It is this reference that ensures the *cohesion* between two sentences

Anaphora

- Hasan (1976) describes *anaphora* as “cohesion which points back to some previous item”
- The ‘pointing back’ word or phrase is called an *anaphor*
- The entity to which an anaphor refers or for which it stands is its *antecedent*
- The process of determining the antecedent of an anaphor is called *anaphora resolution*
- *E.g.,* *The Queen* is not here yet but *she* is expected to arrive in the next half an hour

Coreferential

- When the anaphora refers to an antecedent and when both have the same referent in the real world, they are termed *coreferential*
- Coreference: the act of picking out the same referent in the real world
- Definite noun phrases in copular relation are considered as *coreferential*
- *E.g., John is the second best player in the world*
- Not every indefinite noun phrases triggers coreference

Coreferential Chain

- A specific anaphor and more than one of the preceding (or following) noun phrases may be coreferential thus forming a *coreferential chain* of entities which have the same referent
- *E.g.*, *This book* is about anaphora resolution. *The book* is designed to help beginners in the field and *its* author hopes that *it* will be useful.
- Antecedent: *this book*
- Referent: the actual book being read in the real world
- Anaphor: the NP *the book*, the possessive pronoun *its*, the personal pronoun *it*

Anaphoric and Coreferential

- Bound anaphors which have as their antecedent quantifying NP such as *every man, most computational linguistics* , *nobody, etc.* are examples where the anaphor and the antecedent do not corefer
- Every man has his own destiny

  - the relation is only anaphoric
- John has his own destiny

  - the relation is both anaphoric and coreferential

Anaphor, Antecedent and Referent

- The relation between the *anaphor* and the *antecedent* is not to be confused with the relation between the *anaphor* and its *referent*
- *E.g., The Queen* is not here yet but *she* is expected to arrive in the next half an hour
- The *referent the Queen* is a person in the real world (e.g., Queen Elizabeth) whereas the *antecedent the Queen* is a linguistic form
- An anaphor can be a hypernym of its antecedent

Substitution Test

- A substitution test can be used to establish coreference in (1) resulting in the semantically equivalent sentence in (2)

1. John has his own destiny
2. John has John's destiny

- But the followings are not semantically equivalent
  - Every man has his own destiny
  - Every man has every man's destiny

Identity-of-sense anaphora

- The anaphor and the antecedent do not have the same referent
-
- E.g., The man who gave his paycheck to his wife was wiser than the man who gave it to his mistress

- The anaphor *it* and the antecedent *his paycheck* do not correspond to the same referent in the real world but to one of the similar description

- *It* and *his paycheck* are not coreferential

Identity-of-referent anaphora

- The anaphor and the antecedent denote the same entity
- *E.g.*, *This book* is about anaphora resolution. *The book* is designed to help beginners in the field and *its* author hopes that *it* will be useful.
- The task of anaphora resolution has to do with tracking down an antecedent of an anaphor, whereas coreference resolution seeks to identify the coreference chain
- There may be cases where two items are coreferential without being anaphoric
  - E.g., cross-document reference (two mentions of the same person in two different documents will be coreferential, but will not stand in anaphoric relation)

Varieties of Anaphora according to the form

- Nominal Anaphora
  - Pronominal anaphora
  - Lexical noun phrase anaphora
  - Noun anaphora
  - Verbs anaphora
  - Adverb anaphora
  - Zero anaphora
    - Zero pronominal anaphora
    - Zero noun anaphora
    - Zero verb anaphora
    - Verb phrase zero anaphora (ellipses)

Nominal Anaphora

- Nominal anaphora arises when a *referring expression* (pronoun, definite noun phrase or proper noun) has a non-pronominal noun phrase as its antecedent

Pronominal anaphora

- Pronominal anaphora occurs at the level of *personal pronoun, possessive pronouns, reflexive pronouns, demonstrative pronouns, and relative pronouns*
- The set of anaphoric pronouns consists of all
  - third person personal (*e.g., he, him, she, her, it, they, them*)
  - Possessive (*e.g., his, her, hers, its, their, theirs*)
  - Reflexive (*e.g., himself, herself, itself, themselves*)
  - Demonstrative (*e.g., this, that, these, those*)
  - Relative (*e.g., who, whom, which, whose*)
- *Where* and *when* are anaphoric too for locative and temporal anaphora

Non-anaphoric Pronouns

- The first and second person pronouns are non-anaphoric
- The third person pronouns in English are non-anaphoric when they are in generic use and deictic use
  - He who dares wins. (*generic use*)
  - He seems remarkably bright for a child of his age. (deictic use)
- The pronoun *it* can often be non-anaphoric
  - *It is dangerous to be beautiful.*
- The non-anaphoric use of *it* is referred to as ***pleonastic***
- The automatic identification of pleonastic *it* in English is not a trivial task.

Pleonastic *It : Non-anaphoric*

- *It* appearing in constructions with modal adjectives
  - (*e.g., It is dangerous, It is important, It is necessary, etc*.)
- It in various constructions with cognitive verbs
  - *(e.g., it is believed that …, it appears that…)*
- It appearing in constructions describing weather conditions
  - *(e.g., It is raining, it is sunny, it is drizzling)*
- It in temporal constructions
  - (*e.g., it is five o'clock, it is high time, it is late, what day is it today?*)
- It in constructions related to distance
  - (*e.g., How far is it to Lahore? It is long way from here to Lahore*)
- It in idiomatic constructions
  - (*Stick it out, At least we've made it, How's it going?*)
- It in cleft constructions
  - (*e.g., It was John who recruited Mary*)

Lexical noun phrase anaphora

- **Lexical noun phrase anaphora** is realized syntactically as definite noun phrases (also called *definite descriptions (Russel 1905)*) and proper names
  - Both noses went down to *the footprints* in the snow. *These footprints* were very fresh.
  - *Mary* was nervous on the eve of the party. That is *Mary* for you.
- Certain determiners such as *the, this, these, that,* and *those* signal that the noun phrase they modify is coreferential to a previous noun phrase
- Definite descriptions are not always anaphoric and their generic use is not uncommon
  - No one knows precisely when *the wheel* was invented.
  - George enjoys playing *the piano.*

Noun anaphora

- Noun phrase anaphora should not be confused with **noun anaphora**
- **Noun anaphora-** the anaphoric relation between a non-lexical proform and the head noun of a noun phrase.
- Examples
  - The man who gave his *paycheck* to his wife was wiser than the man who gave *it* to his mistress.
  - I don't think I'll have a sweet *pretzel*, just a plain *one*.

Verbs anaphora

- According to the form of the anaphor, **verb anaphora** need to be mentioned
- Examples
  - Romeo, the Canadian general in charge, *begged for reinforcement*; so *did* Boutros-Ghali.
  - Ex
- The interpretation of *did* is determined by its anaphoric relation to its antecedent in the preceding clause

Adverb anaphora

- **Adverb anaphora:** it can be locative such as *there* or *temporal* anaphora such as *then*
- Examples
  - Will you walk with me to *the garden*? I've got to go down *there*.
  - For centuries archaeologists have argued over descriptions of how Archimedes used concentrated solar energy to destroy the Roman fleet *in 212BC*. Historians have said nobody *then* knew enough about optics and mirrors.

Zero anaphora (or ellipsis)

- Another important class of anaphora according to the form
- The most sophisticated variety of anaphora
- Have the ability to reduce the amount of information to be presented via abbreviated linguistics forms
- Zero anaphors are ‘invisible’ anaphors
- They are not overtly represented by any word or phrase
- Zero anaphora or Ellipsis: The phenomenon associated with the deletion of linguistic forms thus enhancing rather than damaging the coherence of a sentence or a discourse content

Zero Pronominal Anaphora

- *Zero pronominal anaphora* occurs when the anaphoric relation is omitted but is nevertheless understood
- In the above sentence, the third clause features zero pronominal anaphora (the expected full form would have been *but it is nevertheless understood*)
- Example:
  - Mary sang and ø danced in the party.

Zero Noun Anaphora

- Zero noun anaphora arises when the head noun only- and not the whole NP – is elliptically omitted
- The reference is realized by the 'non-omitted', overt modifier
- Typical overt modifiers of zero anaphoric nouns in English are the indefinites: *several, few, some, many, more*
- *Examples*
  - George was bought a huge box of chocolates but few ø were left by the end of the day
  - Jenny ordered three *copies* of the document and Conny ordered several ø too

Zero Verb Anaphora

- Zero verb anaphora arises when the verb is omitted elliptically and the zero anaphor points to a verb in a previous clause or sentence
- Example
  - *Win* a pen or ø a pencil or ø weekend in Paris.

Verb phrase zero anaphora (ellipsis)

- Verb phrase zero anaphora is the omission of a verb phrase which leaves a gap pointing to a verb phrase antecedent, usually in a previous clause
- Enhances the readability and coherence of the text by avoiding repetition
- Example
  - I have never *been to Srilanka* but my father has ø, and he says it was wonderful.
- The antecedent can be elliptically omitted
  - I have not *got a car* myself but Tom has ø, and I think I'll be able to persuade him to let us borrow *it.*

Types of anaphora according to the location

- **Intrasentential** : Intrasentential anaphora arises if the anaphor and its antecedent are located in the same sentence
- Reflexive pronouns are typical examples of intrasentential anaphors
- Personal pronouns and noun phrases acting as intrasentential anaphors usually have their antecedents located in the preceding clauses in the same complex sentence
- **Intersentential :** Intersentential anaphora is exhibited when the antecedent is in a different sentence from the anaphor
- The distinction is of practical importance for the design of anaphora resolution algorithm

Indirect Anaphora

- Indirect anaphora arises when a reference becomes part of the hearer's or reader's knowledge idirectly rather than by direct mention
- Example: Although *the store* had only just opened, *the food hall* was busy and there were long queues at *the tills*.
- *The store* is the antecedent of the indirect anaphor *the food hall* and *the tills*
- *the food hall* is understood to be part of *the store*
- The inference may require more specialized 'domain' knowledge

Direct Anaphora

- Vieira and Poesio (2000) use the term to **direct anaphora** to refer exclusively to the cases when the definite description and the antecedent have identical heads.

- Example
  - Both noses went down to *the footprints* in the snow. *These footprints* were very fresh.

Types of Antecedent

- An anaphor can replace/refer to a noun phrase, verb, verb phrase
- The antecedent of a demonstrative pronoun or the antecedent of the personal pronoun *it* can be a *noun phrase, clause, sentence* or *a sequence of sentences*
  - *John tried to help her with something: this* made indeed for disorder.
  - *They will probably win the match. That* will please my mother.
  - *Many years ago…. Tha*t is why the two men never visit each other's house.
- Anaphors may have **coordinated** antecedents. Anaphor in this case must be plural.
  - The cliff rose high above *Paul and Clara* on their right hand. *They* stood against the tree in the watery silence.

Location of the antecedent

- The distance between an anaphor and its antecedent: not only interesting for theoretical linguistics, but also of practical importance

- It can narrow down the search scope of candidates for antecedents

Anaphora and Cataphora

- Cataphora arises when a reference is made to an entity mentioned subsequently in the text.
  - *She* is now as famous as her ex-boyfriend. From the deserts of Kazakhstan to the south seas of Tonga, everyone knows *Monica Lewinsky.*
- Cataphora is similar to anaphora, the difference being the direction of the pointing.
- Where cataphora occurs, anaphoric reference is also possible by reversing the positions of the anaphora and the antecedent.

Anaphora and Deixis

- **Deixis** is the linguistic phenomenon of picking out a person, object, place, etc. in a specific context or situation.
- He seems remarkably bright for a child of his age.
- *'He'* is not used anaphorically, but deictically.
- *'He'* points to a specific person in a given situation.
- The words typically used in a deictic way
  - Personal pronouns (e.g., *I, we, you*) and their reflexive and possessive counterparts
  - The demonstratives: *this* and *that*
  - The locatives : *here* and *there*
  - *A variety of temporal expressions: now, then today, net week, etc*

Anaphora and ambiguity

- Examples
  - Jane told Mary *she* was in love. (*Jane* or *Mary*?)
  - Jane convinced Mary *she* was in love. (*Jane* or *Mary*?)
  - Jane informed Mary *she* was in love. (*Jane*!)
- The level of ambiguity depends on the semantics of the verb or other components in the sentence or discourse.
- Examples
  - Jane told Mary *she* was in danger. (*Jane*!)
  - Jane warned Mary *she* was in danger. (*Mary*!)

Anaphora Resolution and the Knowledge Required

Anaphora Resolution and the Knowledge Required

- The disambiguation of anaphors is a challenging task and considerable knowledge is required to support it – from low-level morphological and lexical information, to high-level semantic and pragmatic rules.
  - Morphological Knowledge
  - Syntactic Knowledge
  - Semantic Knowledge
  - Discourse Knowledge
  - Real-world Knowledge (common-sense)

Morphological knowledge

- Some anaphors are successfully resolved solely on the basis of lexical information, such as *gender* and *number.*
  - *John* had no letters from Mary while in UK and *he* feared the silence.
- Collective nouns such as *committee, army, team* can be referred to by both *they* and *it*
- Coordinated antecedents such as *John and Mary* are referred to by plural pronouns
- Singular noun phrases that stands for a class can be referred to by plural pronouns in English
  - The jungle was thick. *An animal* may be five yards away and quite invisible, and half of the time *they* manage to dodge past the beaters.

Syntactic Knowledge

- Syntax is indispensable for anaphora resolution
- *John* spoke to Mary and to the associates about a forthcoming project. *The businessman* said this enterprise would cost millions.
- *Syntactic information is essential*: The candidates for antecedent are selected from the noun phrases preceding the lexical NP anaphors *the businessman* or *this enterprise.*
- An anaphora resolution program must have access to a fairly detailed *parser* identifying main and subordinate clauses.

Rules that rely on syntactic information

- *An anaphoric NP is only coreferential with the subject NP of the same simple sentence, clause or phrase when the anaphor is reflexive.*
  - *Jim* is running the business for *himself*.
  - Jim is running the business for him.
- The syntactic constraint prohibits a pronoun in a main clause from coreferring to an NP in a **subsequent** subordinate clause
  - Because *Mary* had saved hard, *she* was finally able to buy the car of her dreams.
  - *Mary* was finally able to buy the car of her dreams, because *She* had saved hard,
  - She was finally able to buy the car of her dreams, because Mary had saved hard.

Semantic Knowledge

- Example:
  - *The petrified kitten* refused to come down from the tree. *It* gazed beseechingly at the onlookers below.
- The gender or number agreement is not of much use because both potential candidates for antecedent of *it* are gender neutral
- The selectional restriction of the verb *gaze* requires its agent to be animate
- Semantic information on the animacy of kitten would be crucial
- Such information reside in a knowledgebase of a computational system

Discourse Knowledge

- Example:
  - Tilly tried on the dress over her skirt and ripped it.
- Neither machines nor humans would be confident in interpreting the anaphoric pronoun *it*
- Example:
  - Tilly's mother had agreed to make her a new dress for the party. She worked hard on the dress for weeks and finally it was ready for Tilly to try on. Impatient to see what it would look like, Tilly tried on the *dress* over her skirt and ripped *it*.
- *Dress* is the most salient entity and is the focus/center of attention throughout the discourse segment.

Intuition behind *focus/center* in a Discourse

- Intuitions:
  - Discourse is normally structured around a central topic.
  - This topic remains prominent for a few sentences before the focal point shifts to a new topic.
  - The center of a sentence (or clause) is typically pronominalized
- The above intuitions affects the interpretation of pronouns
- Once the center has been established, there is often a strong tendency for subsequent pronouns to refer to this center

An illustration

- Discourse A
  1. John works at Citibank.
  2. He works with Lisa.
  3. John is going to marry Lisa.
  4. He is looking forward to the wedding.
- Discourse B
  1. John works at Citibank.
  2. He works with Lisa.
  3. John is going to marry Lisa.
  5. She is looking forward to the wedding.
- Centering Theory predicts that Discourse B is less coherent than Discourse A

Another illustration

- Tuesday morning had been like any other. Lisa had packed her schoolbag, teased her 12-year-old brother James and bossed *her* seven-year-old sister Jane. After breakfast at 8.25 a.m., *she* walked down the stairs of the family's first floor flat and shouted: ' I`m off to school now –bye Mum, bye Dad, I will see you later.'
- The discourse entity *Lisa* is the center in the discourse.
- It is unlikely that any reader would associate *she* with *Jane,* although this is the nearest potential antecedent.
- Obvious fact: 'Very often two or more candidates 'compete' for the antecedent role.
- The task of resolving anaphor can be shifted to the task of tracking down the *focus/center.*

Real-world Knowledge

- Examples:
  - The soldiers shot at *the women* and *they* fell.
  - *The soldiers* shot at the women and they missed.
- The resolution of the above pronominal anaphors will only be possible if further **world knowledge** (common-sense) are available
- Rules:
  - If *X* shoots at *Y* and if *Z (Z* Є {X,Y}) falls, then it is more likely for *Z* to be *Y.*
  - If *X* shoots at *Y* and if *Z (Z* Є {X,Y}) misses, then it is more likely for *Z* to be *X.*
- Many real-life examples of anaphors require world knowledge

Automatic Anaphora Resolution

The Process of Automatic Anaphora Resolution

- The automatic resolution of anaphors consists of the following main stages:
  - Identification of anaphors
  - Location of the potential candidates for antecedents
  - Selection of the antecedent from the set of candidates on the basis of anaphora resolution factors

Identification of Anaphors

- The first step in the process of automatic anaphora resolution
- The antecedents have to be tracked down
- Automatic identification of anaphoric words or phrases in English is not a trivial task

Identification of Anaphoric Pronouns

- In pronoun resolution, only the anaphoric pronouns have to be processed further
- Grammatical information as to whether a certain word is a third person pronoun would not be sufficient
- Non-anaphoric occurrences of the pronoun *it* have to be recognized
- Example: (non-anaphoric *it*)
  - It was a limpid black night, hung as in a basket from a single dull star
- Each occurrence of *it* has to be checked in order to find out if it is referential or not

Identification of pleonastic *it*

- Several algorithms for identification of pleonastic pronouns have been reported in literature
- Lappin and Leass (1994)
  - 'It is ModalAdj that S'
  - 'It is ModalAdj (for NP) to VP'
  - 'It is CogV-ed that S'
  - 'It seems/appears/means/follows (that) S'
  - 'It is not ModalAdj'
  - 'It may be ModalAdj'
  - 'Wouldn't it be ModalAdj'
- Other Algorithms are: Paice and Husk (1987), Denber (1998), Evans (2000, 2001)

Identification of Anaphoric NPs

- The search for anaphoric noun phrases: even more problematic
- *Definite NPs* are potentially anaphoric
  - *Queen Elizabeth* attended the ceremony. *The Queen* delivered a speech.
- Not every definite NPs are anaphoric
  - *Queen Elizabeth* attended the ceremony. *The Queen* delivered a speech. The Duchess of York was there too.
- The definite NPs that are not anaphoric include
  - Definite descriptions that describe a specific, unique entity (as *the Duchess of York*)
  - Definite descriptions used in generic way (as *the wheel* or *the piano*)

Tools and Resources for Identification

- A *program for recognizing pleonastic pronouns or one for identifying non-anaphoric definite descriptions* is required to locate anaphors in English
- A POS tagger is very helpful in an anaphora resolution program
- Enhanced morphological analyzers can also be used if there is no choice.
- The detection of NP anaphors requires at least partial parsing in the form of *NP extraction*
- A *named entity recognizer or a program for identifying proper names* could be of great help
- Zero anaphor identification requires more complete parsing, which reconstructs elliptically omitted items
- *Ontologies* like WordNet may be useful in providing lexical semantics information

Location of the candidates for antecedents

- Once the anaphor is detected, the program has to identify the possible candidates for their antecedent
- Vast majority of systems only handle nominal anaphors since processing anaphors whose antecedents are verbs, clauses, sentences or sequence of sentences is a more complicated task
- All noun phrases preceding an anaphor within a certain ***search scope*** are initially regarded as candidates for antecedents

The **Search Scope** of candidates for Antecedents

- The search scope may vary
  - in size depending on the type of anaphor
  - in form depending on the processing model adopted
- For pronominal anaphors, the search scope is usually limited to the current and two/three preceding sentences
- The search scope is normally longer for definite NPs
- It is *N* preceding sentences (with *N* depending on the type of the anaphor), if there is no means to identify the discourse segment boundaries

Tools and Resources Needed

- A full *parser* can be used for identifying both noun phrases and sentence boundaries
- A *sentence splitter* may be used to single out consecutive sentences
- A *noun phrase extractor* can be useful to retrieve potential candidates for antecedents
- Several knowledge-poor approaches use POS taggers and simple noun phrase grammars to identify noun phrases
- An *unknown word guesser* is very useful to tackle words not found in the dictionary or not identified by POS tagger
- A *proper name recognizer* plays an important role to identify proper name candidates
- Identification of discourse entities requires a *semantic analyzer*

Factors in Anaphora Resolution

- Once the anaphors have been detected, the program will attempt to resolve them by selecting their antecedents from the identified sets of candidates
- The resolution rules based on the different sources of knowledge and used in the resolution process (as the part of the algorithm) are usually referred to as ***anaphora resolution factors***
- Factors frequently used:
  - Constraints
  - Preferences

Constraints

- The following factors can be '*eliminating*', *i.e.*, discarding certain noun phrases from the set of possible candidates
  - Gender and number constraint
  - C-command constraint
  - Semantic (Selectional) restrictions

Gender and Number constraint

- The anaphors and their antecedent must agree in number and gender

- Example:
  - As it is emerged that *Jo Moore* had also tried to launch a ‘dirty tricks’ campaign against London transport supremo Bob Kiley, Downing Street pointedly refused to support *her*.

C-command Constraint

- In intrasentential anaphora resolution, the C-command constraint plays an important role in
  - discounting impossible candidates for antecedents of anaphor that are not reflexive pronouns
  - selecting antecedents for reflexive anaphors
- Examples
  - She almost wanted Mary to know about the affairs.
  - Rajiv's brother like himself.
- Also referred to as configurational constraint (Carter 1987)

Selectional (semantic) Restrictions

- The constraint stipulates that the selectional restrictions that apply to the anaphor should apply to the antecedent as well
- Examples
  - John removed the disk from *the computer* and then disconnected *it.* (The antecedent should be an object that can be disconnected)
  - John removed *the disk* from *the computer* and then copied *it.* (The antecedent should be an object that can be copied)
- This constraint should not be regarded as absolute condition

Preferences

- Preferences: Syntactic parallelism, Semantic parallelism, Salience, Center preference, Subject preference, Proximity, etc.
- Unlike constraints, preferences are not obligatory conditions
- A general (but weak) preference: 'the most recent NP matching the anaphor in gender and number to be the antecedent'
  - Most weekend newspapers these days contain *colour supplements full of rubbish.* It's a waste of time reading *them.*
  - *Most weekend newspapers* these days are full of advertisements. It's a waste of time reading *them.*

Other examples of preference

- preference for *candidates in the main clause* over those in the subordinate clause
- preference for *NPs which are positioned higher in the parse tree* over those that have a lower position
- preference for *candidates in non-adjunct phrases* over those in adjunct phrases

Syntactic Parallelism

- a preference, not a constraint
- helpful when other constraints or preferences are not in a position to propose an unambiguous antecedent
- given to NPs that have the *same syntactic function* as the anaphor
- Examples
  - The programmer successfully combined *Prolog* with C+, but he had combined *it* with Pascal last time
  - The programmer successfully combined Prolog with *C+*, but he had combined Pascal with *it* last time
  - *The program* successfully combined Prolog with C, but Jack wanted to improve *it* further. (- it does not follow this preference)

Center Preference

- **Intuition**: In a coherent discourse, it is the *most salient* and central element in a current clause or sentence that is likely to be pronominalized in a subsequent clause or sentence
- Very strong in pronoun resolution
- Not a constraint, but a preference
- It is the center of the previous clause that is the antecedent of a pronominal anaphor
- Example and counter-example
  - Tilly's mother had agreed to make her a new **dress** for the party. She worked hard on the **dress** for weeks and finally **it** was ready for Tilly to try on. Impatient to see what **it** would look like, Tilly tried on the ***dress*** over her skirt and ripped *it*.
  - It was **Oliver** who persuaded *Joan* to borrow the car. *She* was unaware of the repercussions that later followed.

Subject Preference

- The subject of the sentence is given preference
- Overlaps with center preference since in English the subjects are the favoured sentence centers
- Example
  - *The customer* lost patience and called the waiter. *He* ordered two 12-inch pizaas.
- Not strong enough, easily overruled by common-sense constraints or preferences
  - The customer lost patience and called *the waiter*. *He* apologized, and said *he* had been delayed by other orders.

Illustration of a Model based on Simple Factors

- Consider a simple model using
  - Gender and number agreement constraint
  - The c-command constraint
  - The center preference
- First the constraints are applied and if the antecedents still cannot be determined, the center preference is activated
- Assuming that
  - the analysis has taken place
  - The morphological features of each word are available
  - The syntactic structure of the sentences are available
  - The center of each clause is available
  - All anaphors have been identified

Illustration of a Model based on Simple Factors

- 'How poignant that one of the television tributes paid to Jill Dando shows **her** interviewing people just before the funeral of Diana Princess of Wales. Some of the words **she** used to describe **the late princess** could equally have applied to **her**'
- Four anaphors: her, she, the late princess and her
- Resolution takes place from left to right.
- Initially, all noun phrases preceding the first anaphor *her* are considered potential candidates for antecedents: one of the television tributes , the television tributes , Jill Dando
- The number agreement constraint discounts *the television tributes*

Illustration of a Model based on Simple Factors

- Gender agreement rejects one of the television tributes
- Now Jill Dando is the unambiguous antecedent of *her*
- Next, the anaphor *she*
- Initial candidates: all the preceding NPs
- Gender and number filter eliminate all except *Jill Dando* and *Diana Princess of Wales*
- Now the center preference is taken into account and *Diana Princess of Wales* is rejected
- Next, *the late princess*
- Due to gender and number mismatch this can be resolved only to Jill Dando and *Diana Princess of Wales*
- Now the C-command constraint is activated

Illustration of a Model based on Simple Factors

- Since
  - *she* has been already instantiated to *Jill Dando*
  - *she* C-commands *the late princess*
  - a non-pronominal NP cannot corefer with an NP that C-commands it

  coreference between *Jill Dando* and *the late princess* is impossible
- Now the only antecedent candidate left for *the late princess* is *Diana Princess of Wales*
- Now, the anaphor *her in the second sentence*
- *???*

Theories and Formalisms used in Anaphora Resolution

- Binding Theory (Chomsky 1981, 1995)
- Centering Theory(Grosz *et. al.* 1995)
- Theory of Discourse Structure (Grosz and Sidner, 1986)
- Discourse Representation Theory(Kamp & Reyle 1993)

Examples

- *She likes herself*
- **She$_i$ likes her$_i$.*
- *We gave presents to ourselves.*
- **We gave presents to us.*
- *We gave ourselves presents*
- **We gave us presents.*
- **Lisa told us about us.*
- *Lisa told us about ourselves.*
- **Lisa told ourselves about us.*
- **Lisa told ourselves about ourselves.*

Some Terminology in Binding Theory

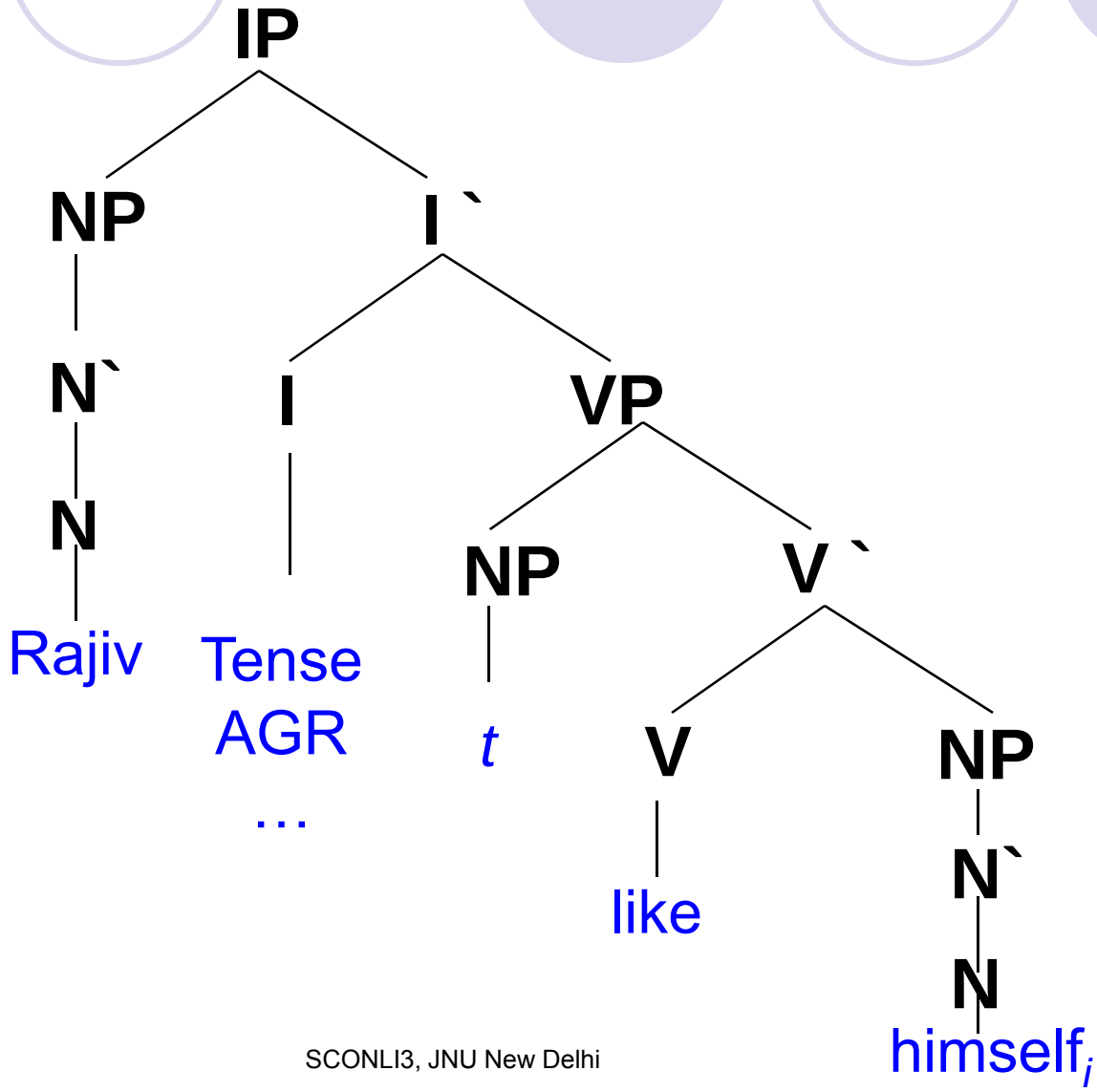
- Binding: The association between a pronoun and an antecedent.
- Anaphoric: A term to describe an element (e.g. a pronoun) that derives its interpretation from some other expression in the discourse.
- Antecedent: The expression an anaphoric expression derives its interpretation from.
- Anaphora: The relationship between an anaphoric expression and its antecedent.

Binding

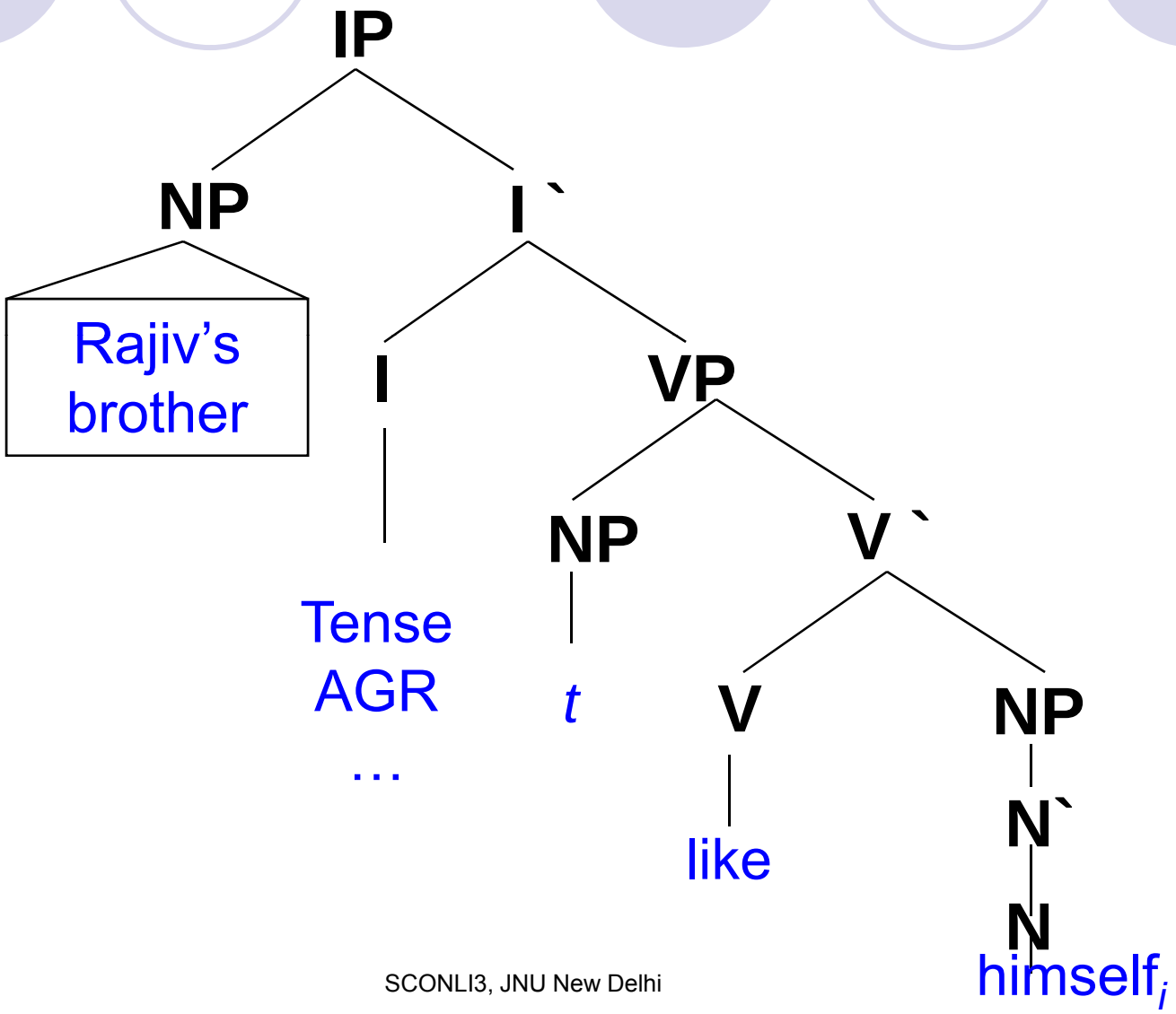
- A relation, called *Binding*
  - α binds β iff
    - α c-commands β
    - α and β are co-indexed

- Rajiv$_i$ likes himself$_i$.

Binding



Binding


IP
NP
I `
Rajiv's brother
I
VP
NP
V `
Tense
AGR
…
t
V
NP
like
N`
N
himself$_i$

Binding

- Example: Rajiv$_i$'s brother$_j$ likes himself$_{*i\ /j}$
- *[Rajiv's brother]* is the antecedent of *[himself]*.
- *[Rajiv]* cannot be the antecedent of *[himself].*
- Example:

  Rajiv$_i$'s brother$_j$ likes *himself*$_{*i\ /j}$ $\neq$

  Rajiv$_i$'s brother likes *Rajiv$_i$*.
- A particular kind of structural relation is maintained between *[Rajiv's brother]* and *[himself],* but not between *[Rajiv]* and *[himself].*
- This structural relation is called

  C(onstituent)-command.

Binding Theory

- For the purpose of interpretation, noun phrases have been conveniently divided into three groups:
  - Bound Anaphors: Reflexives and Reciprocals
  - Pronouns
  - Referential Expressions
- Binding theory is helpful in determining impossible antecedents of pronominal anaphors and in assigning possible antecedents to bound anaphors
- The theory is still an active area of research

Binding Principles

- **Principle A**: A *reflexive* or *reciprocal* is bound in its governing category
  - Rajiv$_i$ likes himself$_i$
- **Principle B**: A pronominal is free in its governing category
  - Rajiv$_i$ likes him$_{*i\,/\,j}$
- **Principle C**: An R-expression is always free
  - John likes Mary

Binding Theory Reformulated in HPSG

- Old Formulation:
  - A reflexive pronoun must be an argument of a verb that has another preceding argument with the same reference.
  - A non-reflexive pronoun cannot appear as an argument of a verb that has a preceding coreferential argument.

- New Formulation:
  - Principle A (version I): A reflexive pronoun must be bound by a preceding argument of the same verb.
  - Principle B (version I): A non-reflexive pronoun may not be bound by a preceding argument of the same verb.

Pronoun-Antecedent Agreement

- The Binding Principles by themselves don't block:
  - * *I amused yourself.*
  - * *He amused themselves.*
  - * *She amused himself.*
- Coindexed NPs refer to the same entity, and Agreement features generally correlate with properties of the referent.
- The Anaphoric Agreement Principle (AAP): Coindexed NPs agree.

Binding in PPs

- What do the Binding Principles predict about the following?
  - *I brought a book with me.*
  - **I brought a book with myself.*
  - **I mailed a book to me.*
  - *I mailed a book to myself.*

Interpretation of Reflexives

- A reflexive anaphor (also called *bound anaphor*)
  - must agree in person, gender and number with its antecedent
  - Must be c-commanded by its antecedent within the local domain
- Examples
  - *Mary* admires *herself*
  - *Mary* likes the photo of *herself*
  - *Mary* believes *herself* to be the most beautiful girl
  - Jane thought the yellow looked better on Sylvia but *Sylvia* wanted to choose for *herself*.

The search scope for reflexives

- Recall *Principle A: An anaphor is bound in its governing category*
- The establishment of the exact local domain (or governing category) in which the reflexive anaphor must be bound is not a trivial matter.
- Local domain very closely described as a minimal clause or a complex NP (e.g., possessive NP)
- Examples
  - [*George* hurt *himself*]
  - John thinks that [*George* hurt *himself*]
  - Peter admires [*Mary's* picture of *herself*]

Interpretation of Personal Pronoun

- The interpretation of Non-reflexive pronominal anaphors differs from that of reflexives
- Examples:
  - *Sylvia* admires *herself*.
  - Sylvia admires *her*.
- *A pronoun cannot refer to a c-commanding NP within the same local domain (*Recall *Principle B)*
- This constraint narrows down the search scope
- Examples:
  - Sylvia admires *her*.
  - Sylvia likes the photograph of *her*.
  - Sylvia told Jane about *her*.
  - *Sylvia* listened to Jane's song about *her*.

Interpretation of Lexical Noun Phrases

- Lexical noun phrases are:
  - the class of noun phrases which are not pronouns (including reflexive or reciprocal)
  - Inherently referential (hence called *referential expressions*)
- So far
  - Reflexive pronouns must be bound locally
  - Non-reflexive pronouns that must be free locally but may be bound outside their local domain
- Now, R-expressions must be free everywhere (Recall Principle B)
- *A non-pronominal NP cannot corefer with an NP that c-commands it*
- Example: Sylvia admires Sylvia

Centering Theory

- A theory about discourse coherence
- Based on the idea that each **utterance** features a topically most prominent entity called a **center**
- Certain entities mentioned in an utterance are more central than others – *this idea imposes certain constraints on the use of referring expressions (particularly on the use of pronouns)*

An illustration

- Discourse A
  1. John works at Citibank.
  2. He works with Lisa.
  3. John is going to marry Lisa.
  4. He is looking forward to the wedding.
- Discourse B
  1. John works at Citibank.
  2. He works with Lisa.
  3. John is going to marry Lisa.
  4. He is looking forward to the wedding.
- Centering Theory predicts that Discourse B is less coherent than Discourse A

Existing Approaches

- Early work
  - Hobbs's Naïve Approach (1976)
- Knowledge-poor and Corpus-based approach (in 1990s & beyond)
  - Collocation pattern-based approach
  - Lappin & Leass's Algorithm
  - Keneddy & Boguraev's Parse-free approach
  - Mitkov's Robust, Knowledge-poor Algorithm

Issues for Continuing Research

- Limits of Anaphora Resolution
  - Limits of the algo and the trade-off between low effort and high performance
  - Methods that heavily exploit knowledge of syntax, semantics, local focusing, world/domain knowledge (accuracy 93%)
  - Knowledge poor methods (accuracy 75%)
- Pre-processing and fully automatic anaphora resolution
  - Inaccurate pre-processing could lead to a considerable drop in the performance
  - POS taggers are reliable, but parsers are not. NER is still a challenge
  - Majority of the existing systems are not fully automatic
- Need of annotated corpora
  - Corpora annotated with anaphoric or corefrential links are still a rare commodity

Sources and Suggested Readings

- Lappin, S. & Leass, H. (1994). 'An algorithm for pronominal anaphora resolution'. *Computational Linguistics,* 20(4)
- Paice, C. and Husk, G. (1987). 'Towards the automatic recognition of anaphoric features in English text: the impersonal pronoun "*it*" '. *Computer Speech and Language, 2*
- Denber, M. (1998). *Automatic Resolution of Anaphora in English*. Internal Report. Eastman Kodak Co.
- Mitkov, Ruslan (2002). *Anaphora Resolution*. Pearson Education.
- Carter, D. (1987). *Interpreting anaphora in natural language texts*. Chichester: Ellis Horwood
- Hobbs, J. (1976). *Pronoun Resolution*. Research Report 76-1. City University of New York.
- Keneddy, C. & Boguraev, B.(1996). 'Anaphora for everyone: pronominal anaphora resolution without a parser'. Proceedings of COLING'96. Denmark

Thank you for your attention!