CS460/626 : Natural Language Processing/Speech, NLP and the Web
(Lecture 33, 34– Binding Theory; Merger)

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(lecture 32 was on IBM model 1 by Anoop)
Motivation

- \( Ram_p \text{ saw himself}_p \text{ in the mirror} \)
- \( *Ram_p \text{ saw himself}_q \text{ in the mirror} \)
- \( Ram_p \text{ saw him}_q \text{ in the mirror} \)
- \( *Ram_p \text{ saw him}_p \text{ in the mirror} \)
- \( \text{The grandmother}_p \text{ of Ram}_q \text{’s distant uncle}_r \text{ saw him}_s \text{ the mirror} \)
- \( *\text{The grandmother}_p \text{ of Ram}_q \text{’s distant uncle}_r \text{ saw him}_p \text{ the mirror} \)
- \( \text{The grandmother}_p \text{ of Ram}_q \text{’s distant uncle}_r \text{ saw herself}_p \text{ the mirror} \)
- \( *\text{The grandmother}_p \text{ of Ram}_q \text{’s distant uncle}_r \text{ saw himself}_p \text{ the mirror} \)
Perspective

Deep understanding level

Interlingual level

Logico-semantic level

Mixing levels

Syntactico-functional level

Syntagmatic level

Morpho-syntactic level

Graphemic level

Ontological interlingua

Semantico-linguistic interlingua

Conceptual transfer

Semantic transfer

Ascending transfer

Multilevel transfer

Syntactic transfer (deep)

Syntactic transfer (surface)

Semi-direct translation

Direct translation

Multilevel description

SPA-structures (semantic & predicate-argument)

F-structures (functional)

C-structures (constituent)

Tagged text

Text

Problem

Language

Parsing

Part of Speech Tagging

Morph Analysis

Hindi

Marathi

English

French

NLP Trinity

Algorithm

CRF

HMM

MEMM

CRE

MEMM

CRF

Algorithm

CRF

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NLP Trinity

1. Deep understanding level
2. Interlingual level
3. Logico-semantic level
4. Mixing levels
5. Syntactico-functional level
6. Syntagmatic level
7. Morpho-syntactic level
8. Graphemic level

- Ontological interlingua
- Semantico-linguistic interlingua
- Conceptual transfer
- Semantic transfer
- Ascending transfer
- Multilevel transfer
- Syntactic transfer (deep)
- Syntactic transfer (surface)
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- Direct translation
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- SPA-structures (semantic & predicate-argument)
- F-structures (functional)
- C-structures (constituent)
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R-Expressions

- Consider the sentence: *Ram found a blanket in the green bag*
  - *Ram, a key in the green bag* are called “Referring Expressions” or “R-expressions”

- Key Definition: An **R-expression** is an entity that gets its meaning by referring to an entity in the world
Not all NPs are R-Expressions

- Ram found himself a blanket in the green bag
  - Himself must refer back to Ram and not to something in the outside world.

- Key Definition: An Anaphor is an NP that obligatorily gets its meaning from another NP in the sentence.
Types of Anaphors

- Reflexive pronouns
  - *Himself, herself, themselves*

- Reciprocals
  - Each other, one another
  - *Ram and Shyam saw each other*
Pronouns

- Get the meaning not necessarily from the same sentence
  - Ram told Shyam that he should collect the blanket
Pronouns with forward reference

- *That he will succeed, was known a priori to Ram*
Anaphors have definite syntactic position

- * himself Ram found a blanket
Coindex and Antecedent

- Definition: An NP that gives its meaning to an anaphor (or pronoun) is called an **Antecedent**
- *Ram found himself a blanket*
  - *Ram*: antecedent
  - *Himself*: anaphor
- Coindexing convention:
  - \([Ram]_i \text{ found } [\text{himself}]_j \text{ a } [\text{blanket}]_k\)
  - \([Ram]_i \text{ told } [\text{Shyam}]_j \text{ that } [he]_k \text{ should collect the } [\text{blanket}]_l\)
- Definition: NPs with the same index are said to be **coindexed** with each other
- Definition: NPs with the same index are said to **corefer** (i.e., refer to the same object in the outside world)
Binding Theory
**Binding**

- The relation between an antecedent and an anaphor/pronoun is a pretty rigid structural relation
  
  - $Ram_i$ found himself$_i$ a blanket
  - *$Ram_i$ found himself$_j$ a blanket
  - *[The servant of Ram]$_i$ found himself$_i$ a blanket
  - *[The servant of Ram]$_j$ found himself$_j$ a blanket
Key Definitions
Domination

- Essentially the specification of a *tree* (very familiar to computer scientists!)
- Axioms of domination ($x \preceq_D y$ means $x$ dominates $y$)
  - (a) $X \preceq_D X$
  - (b) if $X \preceq_D Y \preceq_D Z$ then $X \preceq_D Z$
  - (c) if $X \preceq_D Y \preceq_D X$ then $X = Y$
  - (d) if $X \preceq_D Z$ and $Y \preceq_D Z$ then either $X \preceq_D Y$ or $Y \preceq_D X$ (or both if $X = Y = Z$)
Immediate Domination and Exhaustive Domination

- **Immediate Domination**: Direct Parent Child relation
- **Exhaustive Domination**: Node A exhaustively dominates a set of nodes \{B, C, ..., D\}, if it immediately dominates all the members of the set and there is no node G immediately dominated by A that is not a member of this set.
Constituency

- **Constituent**: A set of nodes exhaustively dominated by a *single* node
- **Constituent-of**: B is a constituent of A iff A dominates B
- **Immediate-constituent-of**: B is an immediate-constituent-of A iff A immediately dominates B
Precedence ("said first" relation)

- S → NP VP
- S dominates NP and VP
- \{NP VP\} forms a constituent
- But NP precedes VP
- Definition: Node A precedes node B iff A is to the left of B and neither A dominates B nor B dominates A and every node dominating A either appears to the left of B or dominates B
No crossing branches constraint

- If one node $X$ precedes another node $Y$ then $X$ and all nodes dominated by $X$ must precede $Y$ and all nodes dominated by $Y$
Axioms of Precedence

- Lets denote precedes by the symbol $\sim$
- (a) If $X \sim Y$ then $\neg (Y \sim X)$
- (b) If $X \sim Y \sim Z$ then $X \sim Z$
- (c) If $X \sim Y$ or $Y \sim X$ then $\neg (X \leq_D Y)$ and $\neg (Y \leq_D X)$
- (d) $X \sim Y$ iff for all terminals $U, V, X \leq_D U$ and $Y \leq_D V$ jointly imply $U \sim V$

No crossing of branch; no discontinuous constituent
Fundamental concept: \textit{c-command}

- (informal): A node \textbf{c-commands} its sisters and all the daughters (and granddaughters and great-granddaughters etc.) of its sisters.

- (formal): Node A \textbf{c-commands} node B if every branching node dominating A also dominates B, and neither A nor B dominate each other.
Example

What does A c-command? What does G c-command?
Example

What does A c-command? What does G c-command?

Ans: A c-commands B and C,D,E,F,G,H,I,J
G c-commands only H
Symmetric C-command and Asymmetric c-command

- A symmetrically c-commands B, if A c-commands B and B c-commands A
- A asymmetrically c-commands B, if A c-commands B and B does not c-command A
Exercise

1. What nodes dominate *grocer*
2. What nodes immediately dominate 
   D3 *the*
3. Do *will* and *buy* form a constituent?
4. What nodes does N₁ *boy* c-command?
5. What nodes does NP₁ c-command?
6. What is V’s mother?
7. What nodes does *will* precede?
8. List all the sets of sisters in the tree.
9. What is PP’s mother?
10. Do NP₁ and VP symmetrically or asymmetrically c-command one another?
11. List all the nodes c-commanded by V

12. What is the subject of the sentence?
13. What is the object of the sentence?
14. What is the object of the preposition?
15. Is NP₃ a constituent of VP?

16. What node(s) in NP₃ an immediate constituent of?
17. What node(s) does VP exhaustively dominate?
18. What is the root node?
19. List all the terminal nodes.
20. What immediately precedes *grocer*?
Correctness and incorrectness of binding

- $Sita_p$ saw herself$_p$ in the mirror.
- $[The\ mother\ of\ Sita_q]_p$ saw herself$_p$ in the mirror.
- *[The mother of Sita$_q$]$_p$ saw herself$_q$ in the mirror.*
From the tree

The mother of Sita saw herself in the mirror.
Case A

S

NP₁

D₁

N₁: The

P₁: mother

PP₁: of

NP₂: Sita

NP₃: N₃ (ANAphor) herself

V: saw

PP₂: in

NP₄: D₂: the

NP₅: N₄: mirror
Case A Observations

- $NP_{mother} \rightarrow$ herself
- $NP_{sita} \rightarrow$ herself
- $NP_{mother} \rightarrow$ her (meaning Sita)
Case B

S

NP₁

N₁ Sita

VP

V saw NP₂

PP₁

P₁ in NP₃

D₁ the N₃ mirror

N₂ (ANA) herself
Case B Observations

- $NP_{sita} \rightarrow$ herself
- $NP_{sita} \rightarrow$ her
Rules

- **Positive Rule of Binding for Anaphor**
  - Anaphor can be bound only to its c-commanding and preceding NP

- **Negative Rule of Binding for Pronoun**
  - Pronoun cannot be bound to a c-commanding NP
Definition of binding

- A binds B if
  - A c-commands B, and
  - A and B are coindexed

- Why is the following wrong?
  - *herself saw Sita in the mirror
Binding domain

- The syntactic space in which the anaphor must find its antecedent is called a *binding domain*.
- Usually the binding domain is the clause.
Significance of binding domain

- *Sita saw herself in the mirror*
- *Sita said that she saw the mirror*
- *Sita said that herself saw the mirror*
- *Sita said that she saw herself in the mirror*
From the tree

S

NP₁

N₁

Sita

VP

V

saw

NP₃

N₃

herself

PP₂

P₂

in

NP₄

N₄

the

mirror
From the tree

S
  VP
    S'
      NP
        V
          said
        NP
          she
    VP
      VP
        V
          saw
        NP
          D₂
            N
            mirror
NP
  N
    Sita
From the tree

S
  /   
/     
VP     S'
  |     |
  V     VP
  said  saw

NP
  |
  N
  Sita

NP
  |
  N
  herself

NP
  |
  D
  the

NP
  |
  N
  mirror
From the tree

S
  VP
    S'
     NP
      V
        said
      NP
        V
          saw
        NP
          P
            in
          NP
            N
              herself
      D_{2}
        N
          mirror
    NP
      N
        Sita
    NP
      N
        she
Binding principle A

- An anaphor must be bound in its binding domain
From the tree
From the tree

S
  VP
    S'
      NP
        N
          Sitap
        NP
          N
            N1
              Shepq
          NP
            V
              said
          VP
            S'
              NP
                V
                  saw
                NP
                  PP
                    P
                      in
                    NP
                      N
                        herr
  NP
    D2
      N
        mirror
Binding principle B

- Definition: *Free*- not bound
- A pronoun must be free in its binding domain.
Binding principle C

- A R-expression (referring expression) must be free.
Which picture of himself does John like?
Merger
Language: Smaller to bigger Expression
Two word phrase
(example from “Linguistics” by Radford et al., Cambridge University Press, 1999)

- Speaker A: What is the Government planning to do?
- Speaker B: Reduce Taxes
- Composed of a verb and a noun, but the behaviour is that of verb
- Why?
  - The Government ought to resign
  - The Government ought to reduce taxes \((\text{substitutibility})\)
  - Taxes is the point of discussion
  - *Reduce taxes is the point of discussion (\text{wrong})
Head and Projection

- *Reduce Taxes*
- A projection of the verb *Reduce*
- Verb Phrase is called the *projection*
- \[ [_{VP} [_{V} reduce] [_{N} taxes]] \]
Infinitive phrase

- Speaker A: What is the Government’s principal objective?
- Speaker B: \textit{to reduce taxes}
- \textit{To reduce taxes} is an \textit{Infinitive Phrase (IP)}

\[
\text{IP} \quad \text{VP} \quad \text{N}
\]

\[
\text{I} \quad \text{reduce} \quad \text{taxes}
\]

\[
\text{to} \quad \text{reduce} \quad \text{taxes}
\]
Head, Complement, Projection

Head

Complement

projection

[IP [I to]][VP [V reduce] [N taxes]]
Larger structures from merger

Striking conclusion: Potentially *Infinite number of sentences in any language*
Phrase to *clause*

- Speaker A: What will the Government do?
- Speaker B: *They will try to reduce taxes*

What is the structure of Speaker B’s reply?

Key question: what to do about *will*?
Similarity of behaviour with \textit{to}

- \textit{To} has similarity with
  - \textit{will/would}
  - \textit{shall/should}
  - \textit{can/could}
  - \textit{may/might}
- Positional similarity
  - \textit{We expect John would/to show some interest}
- Complementiser similarity
  - Need verb in infinitive form: \textit{to/will/would show to a dentist}
Dissimilarity 😞

- To see is to believe
- *Will see is will believe
- Speaker A: What is the Government’s objective?
- Speaker B: to try to reduce taxes
- *will try to reduce taxes
Hypothesis

- *To* produces a complete phrase
- *Will* produces an incomplete phrase
- *Will* needs a subject
- There are other factors playing their roles
Speaker A: What will the Government do?
Speaker B: They will try to reduce taxes
They will reduce taxes to try

 Auxiliaries like *will* produce an Incomplete inflection phrase
 We denote this by I-bar

*To, will etc. are given the label INFL
INFL stands for *Inflection*
Hindi *gaana*, Italian *cantare*
They will try to reduce taxes.