CS395-T
Topics in Natural Language Processing

LECTURE 5

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Parsing Viewed through a Constraint-based Formalism

- Representation mode: feature structures
- Operation: unification

Integration into a grammatical formalism.

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Feature Structures

- Simple way to encode properties
  - Sets of feature-value pairs
- What are the features ?
  - Atomic symbols
  - Representation: attribute-value matrix AVM

$$\begin{bmatrix} \text{Feature}_1 & \text{Value}_1 \\ \vdots & \\ \text{Feature}_n & \text{Value}_n \end{bmatrix}$$

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Concrete Example

- Representing the 3sg NP category

$$\begin{bmatrix} \text{CAT} & \text{NP} \\ \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix}$$

- Representing the 3pl NP category

$$\begin{bmatrix} \text{CAT} & \text{NP} \\ \text{NUMBER} & \text{PL} \\ \text{PERSON} & 3 \end{bmatrix}$$

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Feature-Values

- Features are not limited to atomic symbols as their values

$$\begin{bmatrix} \text{CAT} & \text{NP} \\ \text{AGREEMENT} & \begin{bmatrix} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix} \end{bmatrix}$$

another feature becomes a value !

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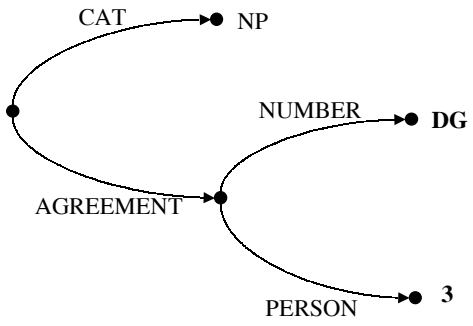
Feature PAth

- A list of features through a feature structure leading to a particular value

  alternative graphical illustration of feature structures



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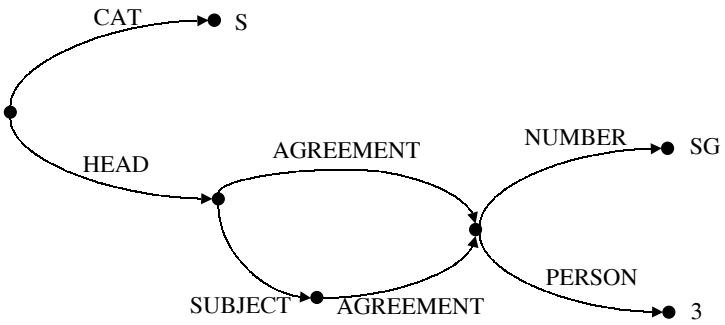
Re-entrancy



A feature structure that shares **values**.

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The Matrix Version

$$\begin{bmatrix} \text{CAT} & \text{S} \\ \text{HEAD} & \begin{bmatrix} \text{AGREEMENT} & \boxed{1} & \begin{bmatrix} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix} \\ \text{SUBJECT} & & \begin{bmatrix} \text{AGREEMENT} & \boxed{1} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

Why use them ?
They allow us to express linguistic generalization in surprisingly compact and elegant ways

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Unification of Feature Structures

- Two principal operations can be performed on feature structures
  a) Merge information content
  b) Reject the merger of incompatible structures

  One computational technique: unification

Example:

[NUMBER SG] ∪ [NUMBER SG] = [NUMBER SG]

$$\begin{cases} \text{[NUMBER SG]} \cup \text{[NUMBER PL]} \textit{ Fails !} \\ \text{[NUMBER SG]} \cup \text{[NUMBER []]} = \text{[NUMBER SG]} \\ \text{[NUMBER SG]} \cup \text{[PERSON 3]} = \begin{bmatrix} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix} \end{cases}$$

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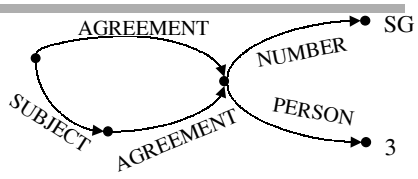
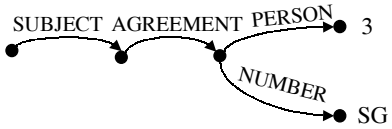
More Complicated Unifications

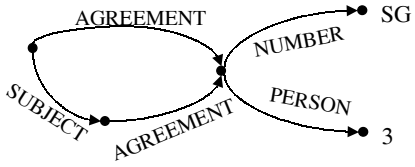
$$\begin{bmatrix} \text{AGREEMENT } \boxed{1} \begin{bmatrix} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix} \\ \text{SUBJECT} \quad \begin{bmatrix} \text{AGREEMENT } \boxed{1} \end{bmatrix} \end{bmatrix}$$



$$\cup \begin{bmatrix} \text{SUBJECT} \quad \begin{bmatrix} \text{AGREEMENT} \begin{bmatrix} \text{PERSON} & 3 \\ \text{NUMBER} & \text{SG} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$



$$= \begin{bmatrix} \text{AGREEMENT } \boxed{1} \begin{bmatrix} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix} \\ \text{SUBJECT} \quad \begin{bmatrix} \text{AGREEMENT } \boxed{1} \end{bmatrix} \end{bmatrix}$$



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Features That Share

$$\begin{bmatrix} \text{AGREEMENT} & [\text{NUMBER SG}] \\ \text{SUBJECT} & [\text{AGREEMENT} \quad [\text{NUMBER SG}]] \end{bmatrix}$$

$$\cup \begin{bmatrix} \text{SUBJECT} & [\text{AGREEMENT} \quad [\text{PERSON 3}, \text{NUMBER SG}]] \end{bmatrix}$$

$$= \begin{bmatrix} \text{AGREEMENT} & [\text{NUMBER SG}] \\ \text{SUBJECT} & [\text{AGREEMENT} \quad [\text{NUMBER SG}, \text{PERSON 3}]] \end{bmatrix}$$

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A failing Example

$$\begin{bmatrix} \text{AGREEMENT} \ \boxed{1} & [\text{NUMBER SG}, \text{PERSON 3}] \\ \text{SUBJECT} & [\text{AGREEMENT} \ \boxed{1}] \end{bmatrix}$$

$$\cup \begin{bmatrix} \text{AGREEMENT} & [\text{NUMBER SG}, \text{PERSON 3}] \\ \text{SUBJECT} & [\text{AGREEMENT} \quad [\text{NUMBER PL}, \text{PERSON 3}]] \end{bmatrix}$$

Fails !

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Feature Subsumption

- Represented by $\subseteq$
- Formal definition:

$$F \subseteq G \Leftrightarrow$$

  - For every feature x in F, $F(x) \subseteq G(x)$
  - For all paths p and q in F s.t.

$$F(p)=F(q) \Rightarrow G(p) = G(q)$$

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Examples

(A) $\begin{bmatrix} \text{NUMBER} & \text{SG} \end{bmatrix}$ (B) $\begin{bmatrix} \text{PERSON} & 3 \end{bmatrix}$

(C) $\begin{bmatrix} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix}$ (D) $\begin{bmatrix} \text{CAT} & \text{VP} \\ \text{AGREEMENT} & 1 \\ \text{SUBJECT} & \begin{bmatrix} \text{AGREEMENT} & 1 \end{bmatrix} \end{bmatrix}$

(E) $\begin{bmatrix} \text{CAT} & \text{VP} \\ \text{AGREEMENT} & 1 \\ \text{SUBJECT} & \begin{bmatrix} \text{AGREEMENT} & \begin{bmatrix} \text{PERSON} & 3 \\ \text{NUMBER} & \text{SG} \end{bmatrix} \end{bmatrix} \end{bmatrix}$

(F) $\begin{bmatrix} \text{CAT} & \text{VP} \\ \text{AGREEMENT} & 1 \\ \text{SUBJECT} & \begin{bmatrix} \text{AGREEMENT} & 1\begin{bmatrix} \text{PERSON} & 3 \\ \text{NUMBER} & \text{SG} \end{bmatrix} \end{bmatrix} \end{bmatrix}$

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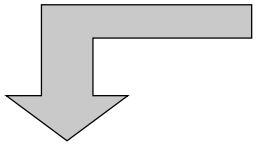
examples



(A) $\begin{bmatrix} \text{NUMBER} & \text{SG} \end{bmatrix}$ (B) $\begin{bmatrix} \text{PERSON} & 3 \end{bmatrix}$

(C) $\begin{bmatrix} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix}$ (D) $\begin{bmatrix} \text{CAT} & \text{VP} \\ \text{AGREEMENT} & 1 \\ \text{SUBJECT} & \begin{bmatrix} \text{AGREEMENT} & 1 \end{bmatrix} \end{bmatrix}$

(E) $\begin{bmatrix} \text{CAT} & \text{VP} \\ \text{AGREEMENT} & 1 \\ \text{SUBJECT} & \begin{bmatrix} \text{AGREEMENT} & \begin{bmatrix} \text{PERSON} & 3 \\ \text{NUMBER} & \text{SG} \end{bmatrix} \end{bmatrix} \end{bmatrix}$

(F) $\begin{bmatrix} \text{CAT} & \text{VP} \\ \text{AGREEMENT} & 1 \\ \text{SUBJECT} & \begin{bmatrix} \text{AGREEMENT} & 1 \begin{bmatrix} \text{PERSON} & 3 \\ \text{NUMBER} & \text{SG} \end{bmatrix} \end{bmatrix} \end{bmatrix}$

- $A \subseteq C$
- $B \subseteq C$
- $D \subseteq E$
- $D \subseteq F$

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Feature structures in the grammar

- Used to express syntactic constraints that would be difficult by using context-free grammars alone.
- **Question:** How can feature structures and unification be integrated in the specification of a grammar?
  - By augmenting the rules of a regular grammar with attachments that specify feature structures for the constituents of the rules.
  - Is this all? No – use also appropriate unification operations.

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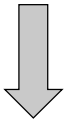
Example

- S → NP VP
- Only if the number of the NP is equal to the number of the VP



- S → NP VP
- <NP NUMBER> = <VP NUMBER>

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Head features

- Observation:
  - a general phenomenon of constraint-based grammars
  - → the features of most grammatical categories are copied from one of the children to the parent.

  What child? The head of the phrase.
- **Examples**:
  - VP → Verb NP
    - <VP AGREEMENT> = <Verb AGREEMENT>
  - NP → Det Nominal
    - <Det AGREEMENT> = <Nominal AGREEMENT>
    - <NP AGREEMENT> = <Nominal AGREEMENT>
  - Nominal → Noun
    - <Nominal AGREEMENT> = <Noun AGREEMENT>

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Rewrite the rules with a HEAD feature

- VP → Verb NP
  - <VP HEAD> = <Verb HEAD >
- NP → Det Nominal
  - <NP HEAD > = <Nominal HEAD >
  - <Det HEAD AGREEMENT> = <Nominal HEAD AGREEMENT>
- Nominal → Noun
  - <Nominal HEAD > = <Noun HEAD >

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Subcategorization

- Recap: verbs can be picky about the patterns of arguments they will allow themselves to appear with.
- SUBCAT feature
  - Verb → serves
    - <Verb HEAD AGREEMENT NUMBER> = SG
    - <Verb HEAD SUBCAT> = TRANS
  - VP → Verb
    - <VP HEAD> = <Verb HEAD >
    - <VP HEAD SUBCAT> = INTRANS
  - VP→ Verb NP
    - <VP HEAD> = <Verb HEAD >
    - <VP HEAD SUBCAT> = TRANS
  - VP→ Verb NP NP
    - <VP HEAD> = <Verb HEAD >
    - <VP HEAD SUBCAT> = DITRANS

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Subcategorization frames

Noun Phrase Types		
There	nonreferential there	**There** *is still much to learn*
It	nonreferential it	**It** *was evident that my ideas*
NP	noun phrase	*As he was relating* **his story**
Preposition Phrase Types		
PP	preposition phrase	*couch their message* **in terms**
Pping	gerundive PP	*censured him* **for not having intervened**
PPpart	particle	*turn it* **off**
Verb Phrase Types		
VPbrst	bare stem VP	*she could* **discuss it**
VPto	to-marked infin. VP	*Why do you want* **to know***?*
VPwh	wh-VP	**it is worth considering how to write**
VPing	gerundive VP	*I would consider* **using it**

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Subcategorization frames

Complement Clause Types		
Finite Clause		
Sfin	finite clause	*maintain* **that the situation was unsatisfactory**
Swh	wh-clause	*it tells us* **where we are**
Sif	whether/if clause	*ask* **whether Aristophanes is depicting a**
Nonfinite clause		
Sing	gerundive clause	*see* **some attention being given**
Sto	to-marked clause	*know* **themselves to be relatively unhealthy**
Sforto	for-to clause	*She was waiting* **for him to make some reply**
Sbrst	bare stem clause	*commanded* **that his sermons be published**
Other Types		
AjP	adjective phrase	*thought it* **possible**
Quo	quotes	*asked* **"What was it like?"**

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Example: subcategorization patterns for the verb ask

Subcat	Example
Quo	asked [$_{Quo}$"What was it like?"]
NP	asking [$_{NP}$ a question]
Swh	asked [$_{Swh}$ what trades you're interested in]
Sto	ask [$_{Sto}$ him to tell you]
PP	that means asking [$_{PP}$ at home]
Vto	asked [$_{Vto}$ to see a girl called Evelyn]
NP Sif	asked [$_{NP}$ him] [$_{Sif}$ whether he could make]
NP NP	asked [$_{NP}$ myself] [$_{NP}$ a question]
NP Swh	asked [$_{NP}$ him] [$_{Swh}$ why he took time off]

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Long-Distance Dependencies

- **Examples**:
  - What cities does Continental serve?
  - What flights do you have from Boston to Baltimore?
  - What time does that flight leave Atlanta?

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Implementing Unification

- Features can be represented as directed acyclic graphs (DAGs)
  - features = directed edges
  - values = atoms | DAGs

⇒The unification is a graph matching algorithm.

- Unification Data Structures
  - extended DAG – content field
    - pointer field

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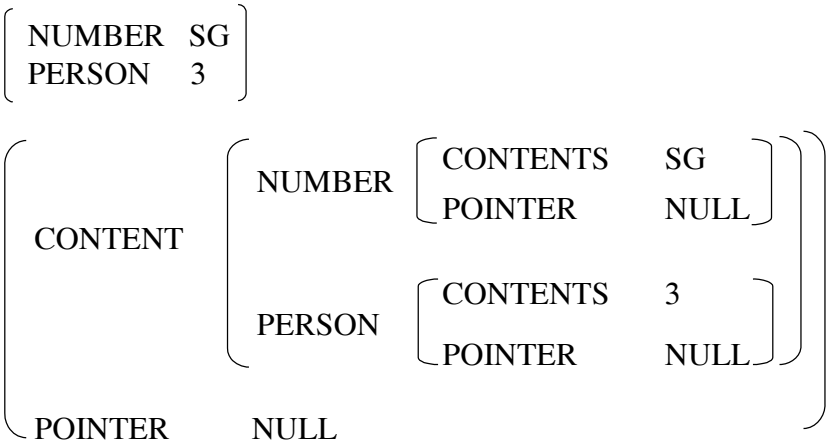
Example



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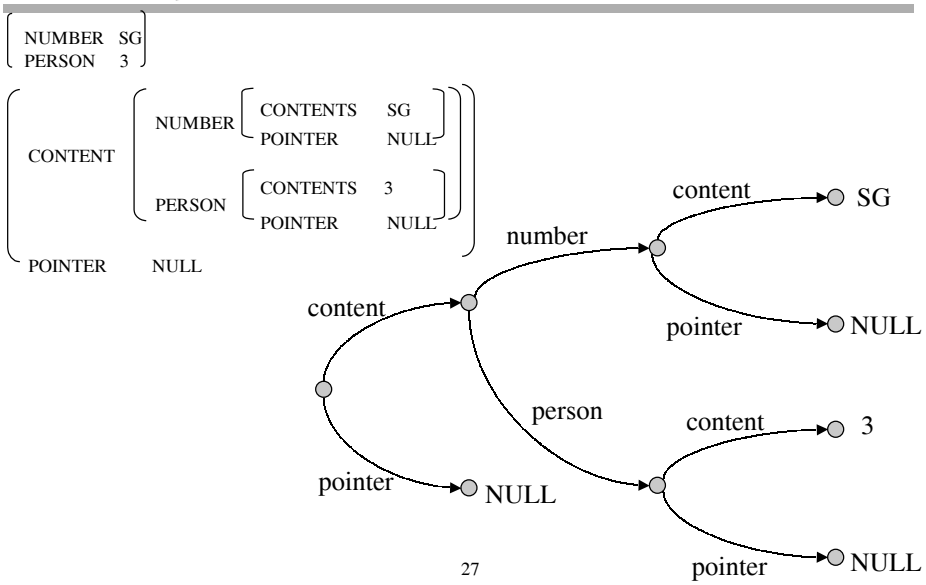
The graph



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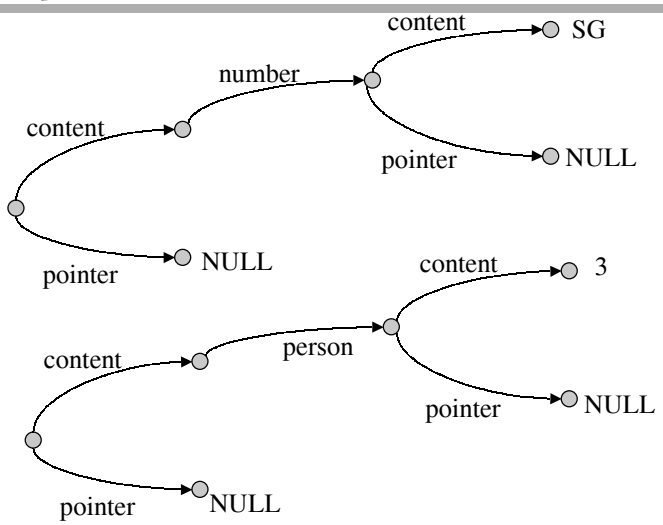
Example



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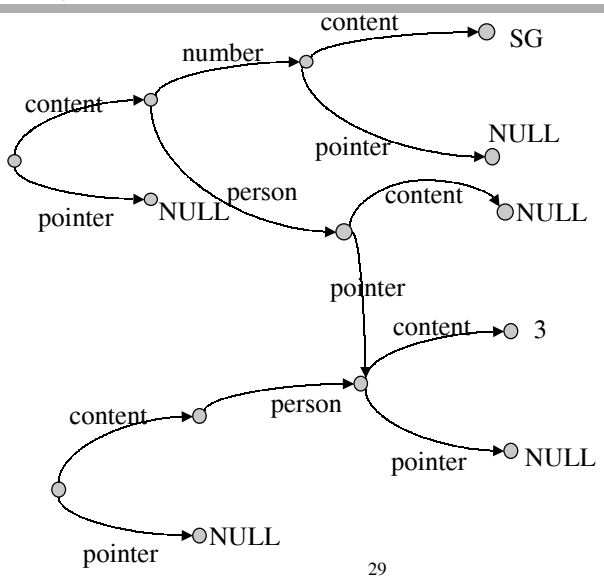
Using pointers



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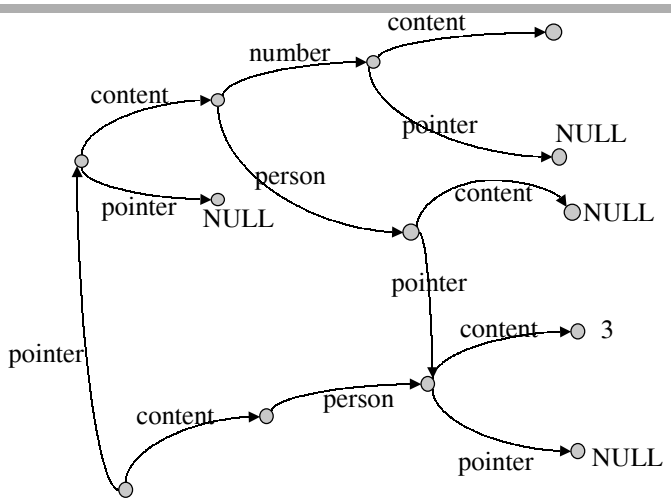
The result



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Dereferencing

- If the POINTER field of an extracted feature structure is not NULL, the real content of that structure is found by following the pointer from the POINTER field

  → also called Real Contents

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The Unification algorithm

```
function UNIFY(f1,f2) returns fstructure or failure
 f1-real ← Real contents of f1
 f2-real ← Real contents of f2
 if f1-real is null then
    f1.pointer ← f2
    return f2
 else if f2-real is null then
        f2.pointer ← f1
        return f1
      else if f1-real and f2-real are identical then
             f1.pointer ← f2
             return f2
           else if both f1-real and f2-real are complex feature structures then
                  f2.pointer ← f1
                  for each feature in f2-real do
                      other-feature ← Find or create a feature corresponding to feature f1-real
                      if UNIFY(feature.value, other-feature.value) returns failure then
                         return failure
                  return f1
                else return failure
```

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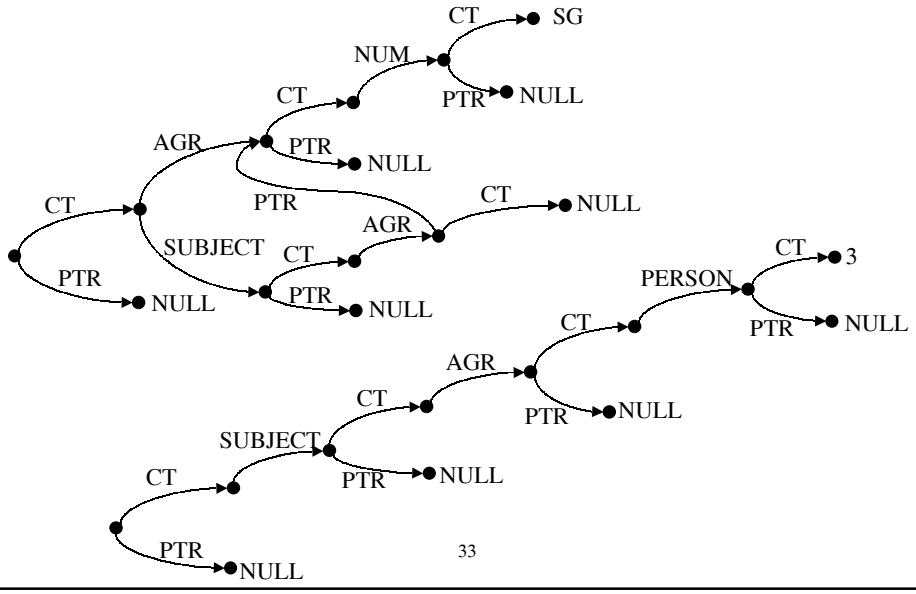
Walk Through an Example



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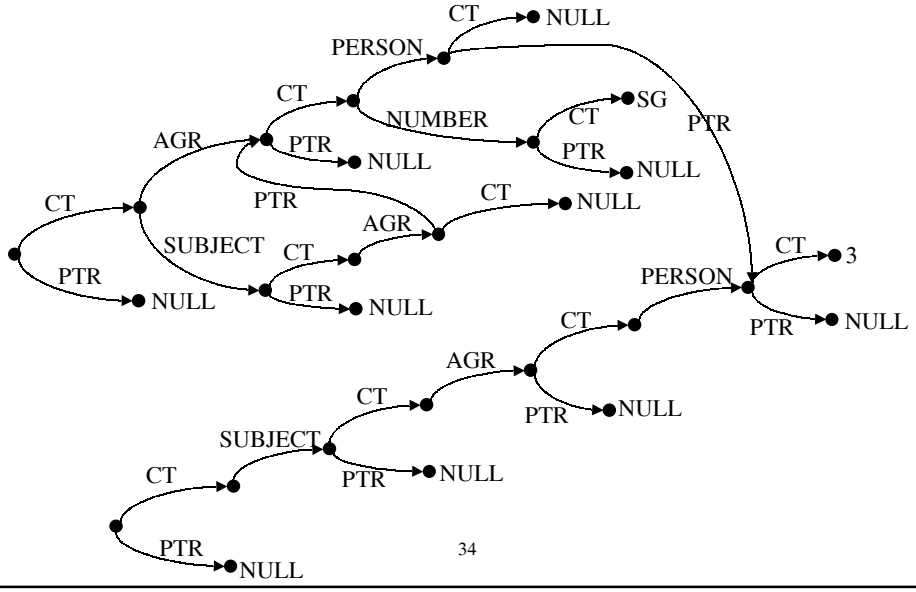
Walk Through an Example



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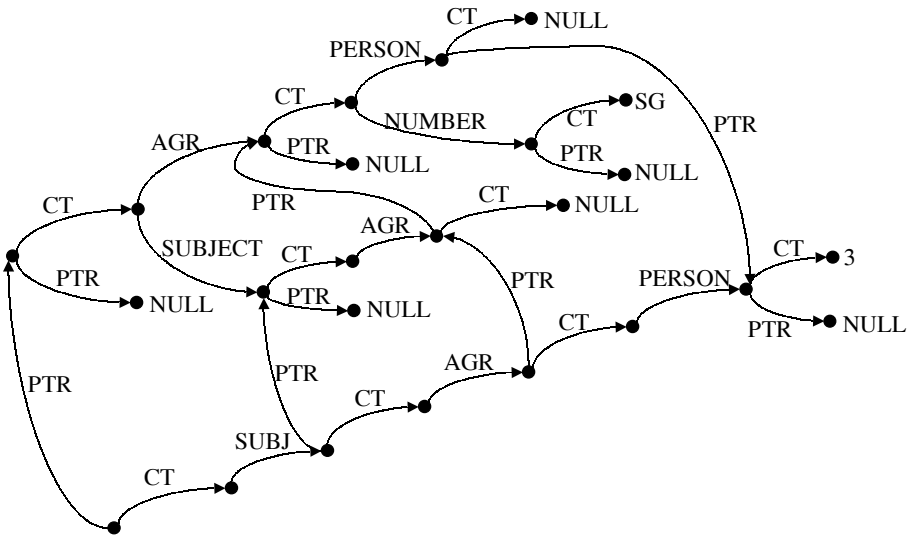
Walk Through an Example



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Parsing with Unification Constraints

1) Integrating unification into an Earley Parser.

   One of the topics of the Current Issues Discussion.

   1. Presenter
   2. Argues

   ⇒ Volunteers ?

   Textbook pages 427 – 437

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