Historical Background: Incremental Processing and the Strict Competence Hypothesis

Vera Demberg

Universität des Saarlandes

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Today

Lecture with interactive component

after each section, we pause 5 min, pairwise discuss introduced concepts, take notes.

Introduction

The Historic Discussion ('80s / '90s).

1. Introduction
2. The Paradox (Steedman)
3. Suggested Solution 1: Change notion of constituents (Steedman)
4. Suggested Solution 2: Less Strict Competence Hypothesis (Stabler)
5. Comparison of Parsing Strategies (Abney & Johnson)
6. Suggested Solution 3: Asynchronous Processing (Shieber & Johnson)

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Introduction

- **Main players** in the debate:
  Mark Steedman, Ed Stabler, Steven Abney, Mark Johnson, Stuart Shieber
- **When?** 1988-1993
- **Question:** *what's a psycholinguistically plausible parsing mechanism?*
- **Criteria:** parsing mechanism should
  - explain linguistic constraints on language
  - explain processing difficulties (e.g. center embedding)
  - account for incremental interpretation (e.g. fast ambiguity resolution)
  - exhibit simple relationship between grammar and processor (Occam's razor)

Background: Definitions (1)

Constituents = “grammatical entities”

A constituent is a word or a group of words that functions as a single unit within a hierarchical structure.

Some constituency tests:

1. Substitution ([The man] knows [the dog that barks].)
2. Deletion (He knows the dog [that barks].)
3. Movement (He attends a course [to improve his German].)
4. Coordination (He [cooked dinner] and [went to bed].)
5. Question-test ([Who] cooked dinner? Maria)

Background: Definitions (1)

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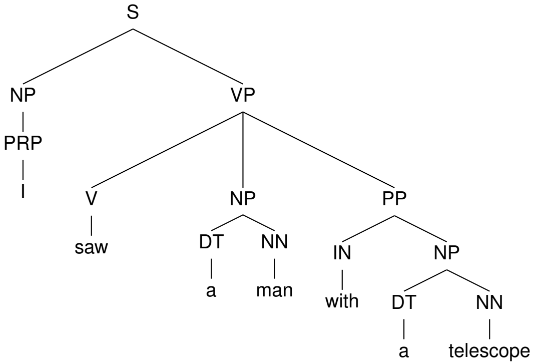
Constituents are reflected directly in the syntactic structure we assign to a sentence:



[I] [[saw] [a man] [with [a telescope]]]

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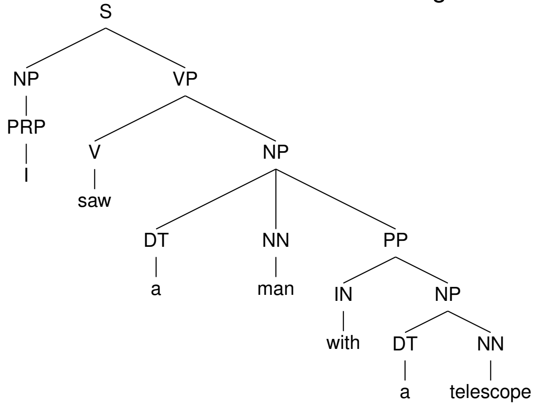
A constituent is a word or a group of words that functions as a single unit within a hierarchical structure.

Ambiguous sentences can have alternative constituent assignments:



Background: Definitions (2)

Incremental Interpretation

Semantic interpretation in human sentence processing can occur before sentence boundaries, and even before constituent boundaries. Some psycholinguistic evidence indicates that semantic interpretation in fact occurs on a word-by-word basis (or maybe even more incrementally).

Background: Definitions (3)

Competence

Competence is the **’ideal’ language system** that makes it possible for speakers to produce and understand an infinite number of sentences in their language, and to distinguish grammatical sentences from ungrammatical sentences.

Performance

Linguistic performance is governed by **principles of cognitive structure** such as memory limitations, distractions, shifts of attention and interest, and (random or characteristic) errors.

Distinction introduced by Noam Chomsky (1965)

- **Linguistics** is concerned primarily with **competence**
- **Psychology** is concerned primarily with **performance**

What’s the relationship between the two?

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Background: Definitions (4)

Strong Competence Hypothesis (Bresnan and Kaplan, 1982)

The Strong Competence Hypothesis of asserts that there exists a direct correspondence between the rules of a grammar and the operations performed by the human language processor.

+

Rule-to-Rule Assumption (Bach, 1976)

Each syntactic rule corresponds to a rule of semantic interpretation.
(⇒ entities combined by syntactic rules must be semantically interpretable)

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Strict Competence Hypothesis (Steedman, 1992)

Structures manipulated by the processor are isomorphic to the constituents listed in the grammar.

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Strict Competence Hypothesis (Steedman, 1992)

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Time for discussion and notes

Discuss pairwise to make sure you understood the following concepts:

- a constituent
- incremental interpretation
- competence
- performance
- strong / strict competence hypothesis

If you've trouble with any of them, please don't feel shy to ask!
We want to discuss these before proceeding to the rest of the lecture.

Timeline of debate

1989 Mark Steedman brings up “Paradox” of three assumptions

- Incremental Interpretation
- Syntax Theories with Right-Branching Structures
- Strict Competence Hypothesis

and argues for bottom-up parsing and new notion of constituents.

1991 Edward Stabler replies that paradox is not really valid

1991 Steven Abney and Mark Johnson argue against both top-down and bottom-up parsing strategies

1992 Mark Steedman replies to criticisms by Stabler

1993 Alternative proposal by Shieber and Johnson (opposing both Stabler and Steedman)

Table of Contents

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In detail: What's the Paradox?

Mark Steedman brings up "Paradox" of three assumptions

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Example (following pattern of *The horse raced past the barn fell*.)

a) The doctor sent for the patients arrived. (more difficult)

b) The flowers sent for the patients arrived. (less difficult)

- If b) is easier, this indicates that the processor has figured out at the point of "sent" that *flowers* cannot be the agent of a sending action.
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Ways out of the paradox

Paradox – can't simultaneously have:

- Incremental Interpretation
- Syntax Theories with Right-Branching Structures
- Strict Competence Hypothesis

Way out: Drop or weaken at least one of the assumptions!

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Steedman

- Incremental Interpretation
- ~~Syntax Theories with Right-Branching Structures~~ **CCG**
- Strict Competence Hypothesis

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Stabler

- Incremental Interpretation
- Syntax Theories with Right-Branching Structures
- ~~Strict~~ Competence Hypothesis

Time for discussion and notes

What constitutes the paradox?

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What is Steedman's solution?

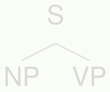
For parsing process (performance), what do we require minimally?

1. a competence grammar
2. an algorithm
3. a stack (memory)
4. an oracle (to resolve non-determinism)

How little else can we get away with? top-down vs. bottom-up processing:

Top-down processing

Step 1:



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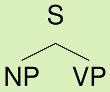

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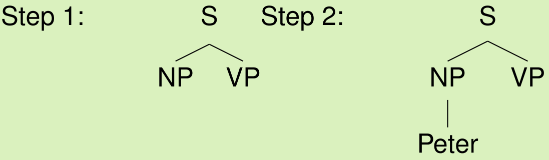

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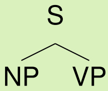

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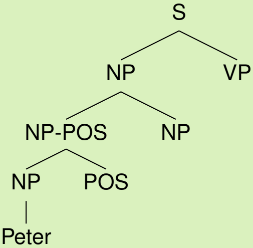

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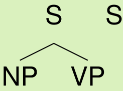

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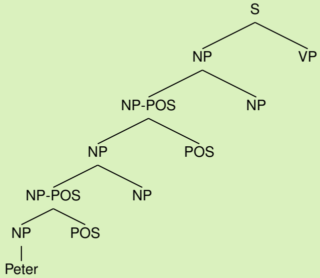

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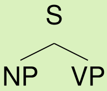

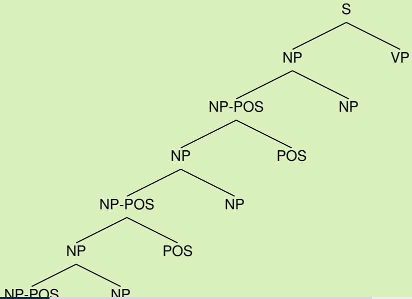

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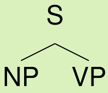

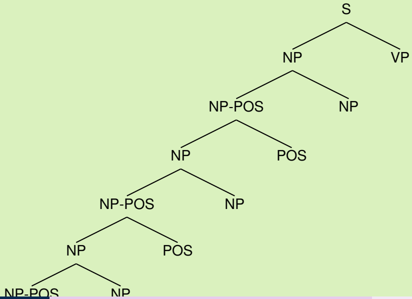

Top-down algorithm needs a special watchdog to deal with left-recursive rules.

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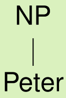

NP

Peter

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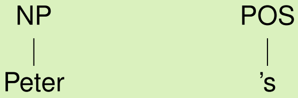

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POS

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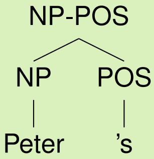

Don’t have the infinity problem...

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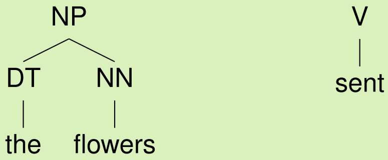
... but can't do incremental interpretation if syntactic structures unconnected.



So how does Steedman solve paradox?

Remember our problem:

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   ⇒ more generally: where constituent structure is left branching

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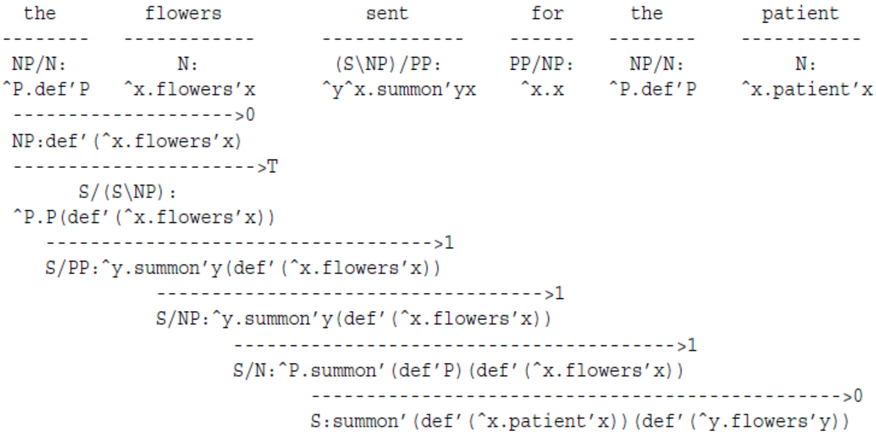
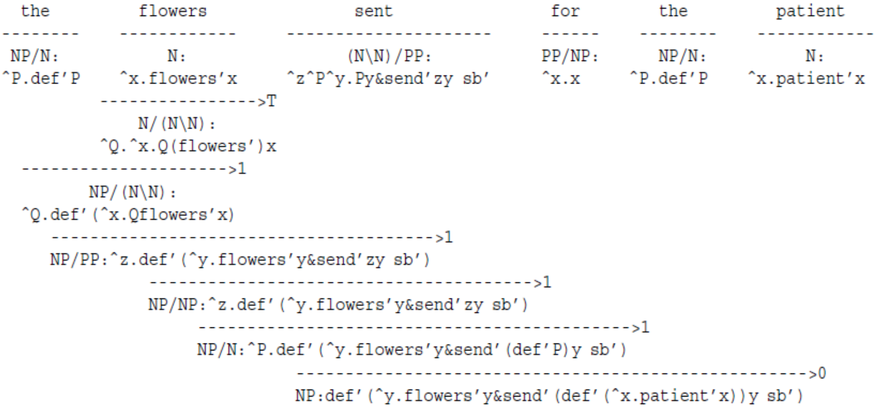


```
  the        flowers             sent            for      the         patient
--------   ------------      -------------    ------    --------    -----------
 NP/N:          N:             (S\NP)/PP:     PP/NP:     NP/N:               N:
^P.def'P   ^x.flowers'x      ^y^x.summon'yx     ^x.x    ^P.def'P    ^x.patient'x
 -------------------->0
 NP:def'(^x.flowers'x)
 ---------------------->T
       S/(S\NP):
 ^P.P(def'(^x.flowers'x))
    ----------------------------------->1
    S/PP:^y.summon'y(def'(^x.flowers'x))
              ----------------------------------->1
              S/NP:^y.summon'y(def'(^x.flowers'x))
                     ----------------------------------------->1
                     S/N:^P.summon'(def'P)(def'(^x.flowers'x))
                            ------------------------------------------------->0
                            S:summon'(def'(^x.patient'x))(def'(^y.flowers'y))
```

Figure: Incremental CCG derivation (Figure taken from McConville's PhD thesis.)

So how does that work?



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  the         flowers               sent                for        the         patient
--------    ------------     ---------------------     ------    --------    ------------
 NP/N:           N:                 (N\N)/PP:          PP/NP:      NP/N:          N:
^P.def'P    ^x.flowers'x     ^z^P^y.Py&send'zy sb'     ^x.x      ^P.def'P    ^x.patient'x
          ---------------->T
              N/(N\N):
          ^Q.^x.Q(flowers')x
  --------------------->1
         NP/(N\N):
  ^Q.def'(^x.Qflowers'x)
     --------------------------------------->1
     NP/PP:^z.def'(^y.flowers'y&send'zy sb')
               --------------------------------------->1
               NP/NP:^z.def'(^y.flowers'y&send'zy sb')
                    --------------------------------------------->1
                    NP/N:^P.def'(^y.flowers'y&send'(def'P)y sb')
                              ---------------------------------------------------->0
                              NP:def'(^y.flowers'y&send'(def'(^x.patient'x))y sb')
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Figure: Incremental CCG derivation (Figure taken from McConville's PhD thesis.)

Time for discussion and notes

According to Steedman

- What's the trouble with CFG top-down processing?
- What's the trouble with CFG bottom-up processing?
- How does he suggest to solve the paradox?
- Why/How does his suggestion satisfy
  1. Incremental Interpretation
  2. Being a sensible competence grammar
  3. the Strict Competence Hypothesis

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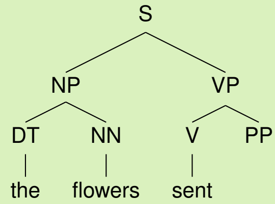
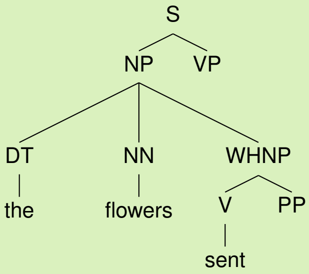
What are Stabler's arguments against the paradox?

- Strict competence hypothesis is unnecessarily strict.
- Parser can be constructed to combine semantics for non-constituents / incomplete constituents

Top-down parsing



$sent'(x,(the'(flowers')))$



$x((the'(flowers'))\&sent'(y,flowers',somebody'))$

why should one need to wait till x and y have been instantiated??

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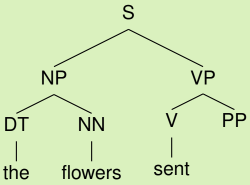

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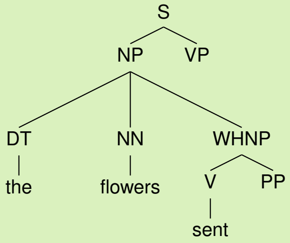

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why should one need to wait till x and y have been instantiated??

⇒ Less complex architecture, don't need mechanism for dealing with partial semantic structures.

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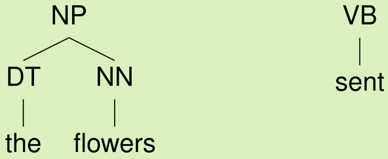
Bottom-up parsing

Stabler suggests to change notation for semantics from prefix to postfix notation, but this still **requires establishing semantic relation where no syntactic relation has been determined**.



Several people have argued that his approach does not logically work out, so we're going to skip it here.

Time for discussion and notes

What's Stabler's argument against the paradox?

In how far is his interpretation of the competence hypothesis less strict?

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What are Abney and Johnson's arguments against top-down and bottom-up parsing?

Motivation #1: Which parsing strategy can explain processing difficulty phenomena such as **center embedding**?

Center embedding

a) The rat that the cat that the dog chased bit ate the cheese.
b) The dog chased the cat that bit the rat that ate the cheese.

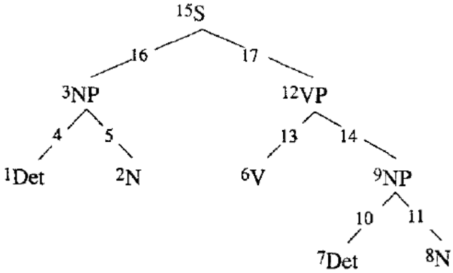
Observations:

- a) is much more difficult to understand than b).
- a) requires holding too many incomplete substructures in memory.

Motivation #2: There's a trade-off between space requirements and amount of local ambiguity for parsing strategies – Is there an optimum?

Parsing Strategies – Size of stack

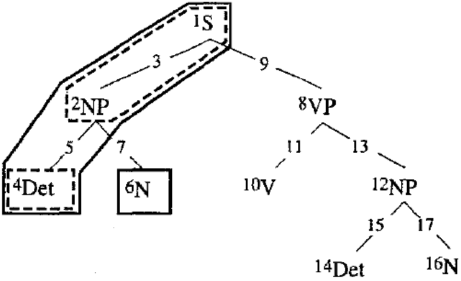
Bottom up



i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
$f(i)$	1	2	3	2	1	2	3	4	5	4	3	4	3	2	3	2	0

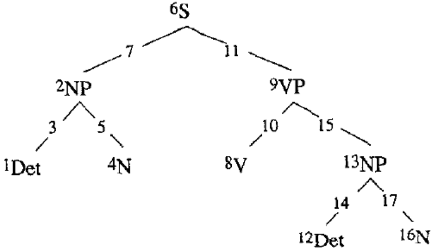
Parsing Strategies – Size of stack

Top down



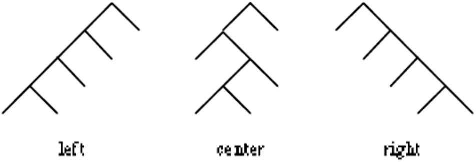
i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
f(*i*)	1	2	2	3	2	3	1	2	1	2	1	2	1	2	1	2	0

Parsing Strategies



Left corner arc-eager parsing order

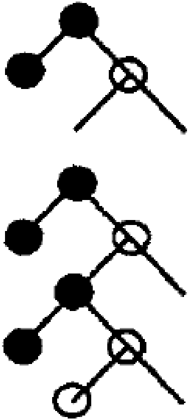
Space requirements for parsing strategies



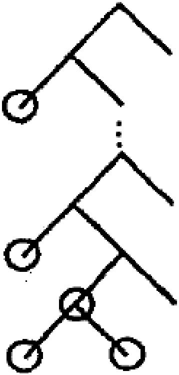
Structure	left	center	right
top-down	n	n/2 + 1	2
bottom-up	3	n/2 + 2	n+1
left-corner	2	n/2 + 1	3

Only left-corner strategy correctly predicts that center embedding structures are most difficult.

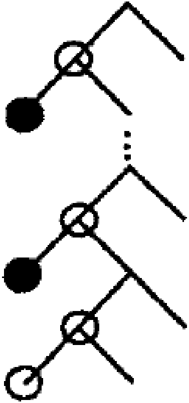
Center-embedding



top-down



bottom-up

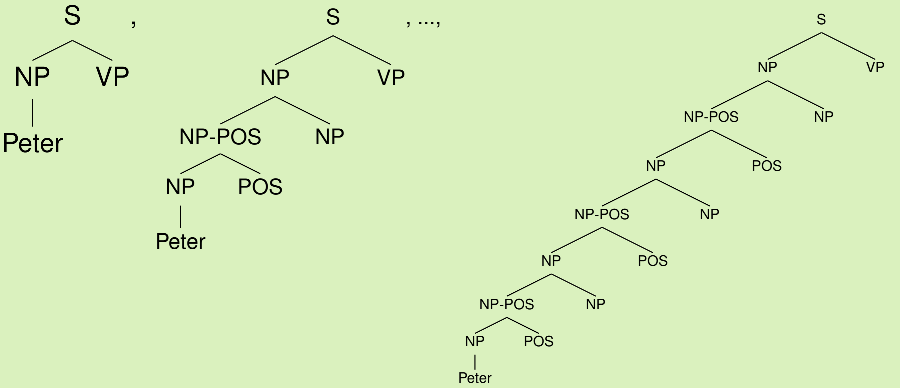


left-corner

Amount of local ambiguity

Top-down strategy incurs much higher local ambiguity than either left-corner or bottom-up strategy.

Remember the left-recursion problem



Time for notes

Discuss in pairs:

- What is center embedding?
- Can you explain why which parsing strategy takes how much space for left branching / center embedded / right branching structures?
- What does this have to do with ambiguity?

Table of Contents

1 Introduction

2 The Paradox (Steedman)

3 Suggested Solution 1: Change notion of constituents (Steedman)

4 Suggested Solution 2: Less Strict Competence Hypothesis (Stabler)

5 Comparison of Parsing Strategies (Abney & Johnson)

6 Suggested Solution 3: Asynchronous Processing (Shieber & Johnson)

What is Shieber and Johnson's alternative?

How Shieber and Johnson propose to **solve the Paradox**

- similar idea as Stabler: ~~strict~~ competence hypothesis
- but very different realization of the idea
- key idea: **asynchronous processing**
- strict competence requires synchronous processing
- **asynchronous processing simpler** since doesn't require synchronization mechanism
- using Synchronous Tree-Adjoining Grammar (S-TAG)

Asynchronous Processing

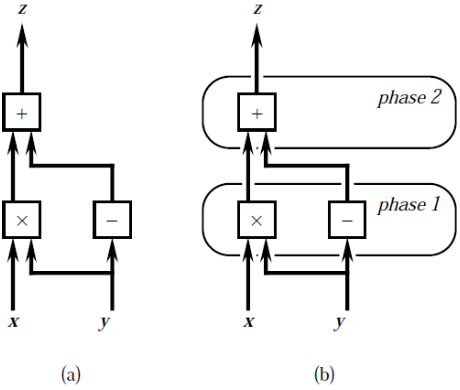
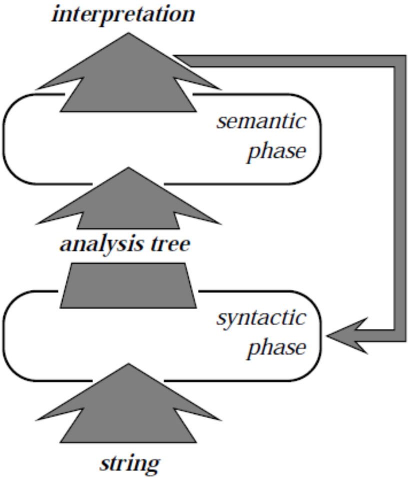


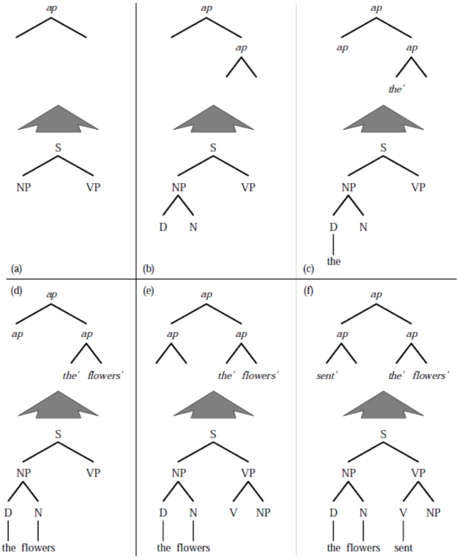
Figure: Circuit for computing $z = xy + (-y)$

- (a) asynchronous process
- (b) synchronous process
- in some conditions, (a) can calculate z with only one of the inputs
- Examples: y=0 or x=1

Applying the idea to human sentence processing



Asynchronous Processing Top-Down

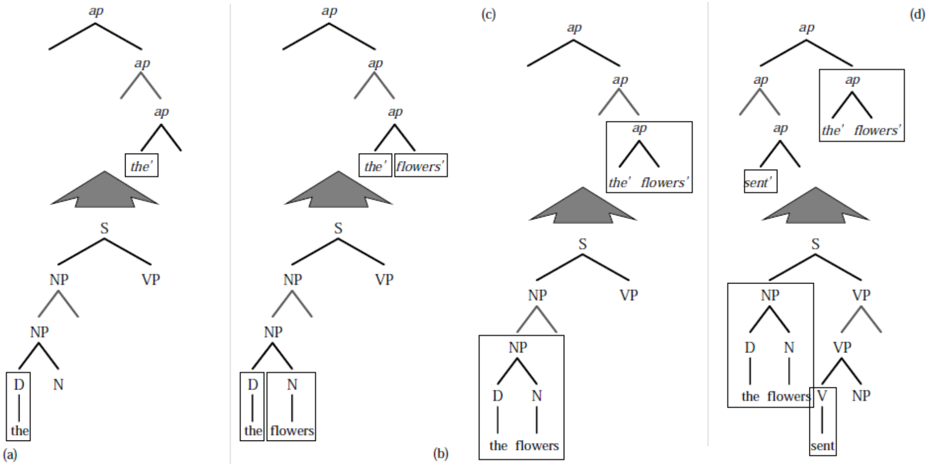


We achieve Incremental Interpretation in top-down processing.

But note:

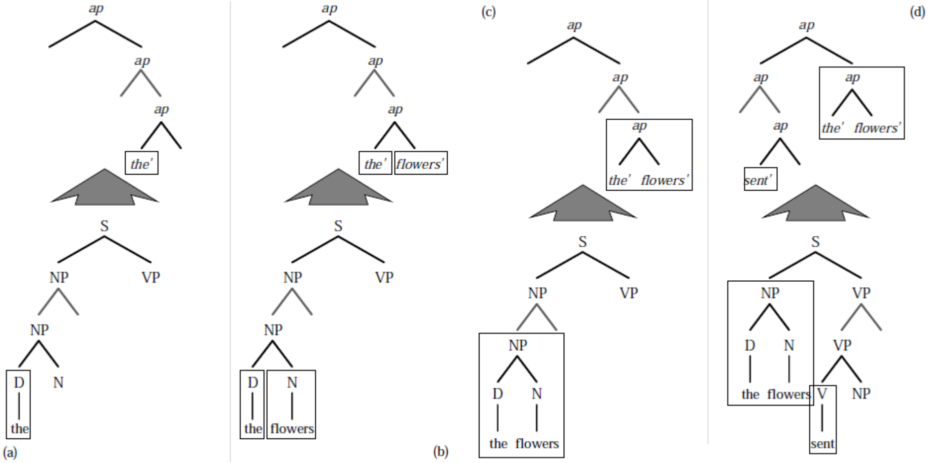
- this does not resolve left recursion
- or center embedding problem
- or large ambiguity (early commitment to structure)

Asynchronous Processing Bottom-Up



- boxed structures is what the parser has actually built
- unboxed structures are defined by equivalence classes

Asynchronous Processing Bottom-Up



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Asynchronous Processing Bottom-Up

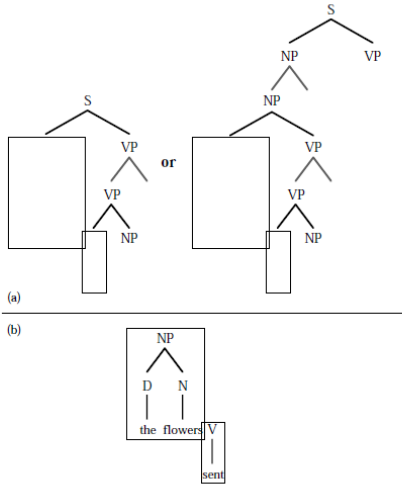


Figure: Syntax

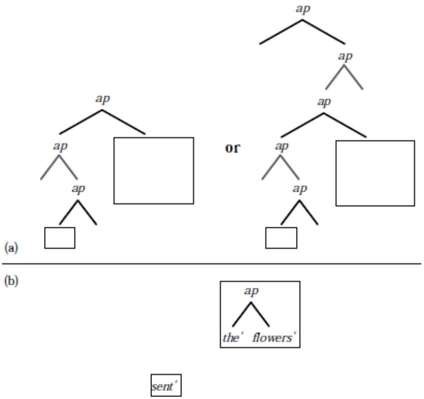


Figure: Semantics – Now parser can decide to discard the first interpretation. How can we reasonably calculate all those equivalence structures (outside boxes)?

Critique on Shieber and Johnson's approach

Critique: **extra machinery to inspect internal state of parser**

syntax-semantic interface much simpler if syntactic relations are explicit and not implicit (⇒ need compiled version of competence grammar so we know instantly what structures are possible)

Time for discussion and notes

Discuss in pairs

- What is asynchronous processing?
- How is incremental interpretation achieved in top-down processing?
- How is incremental interpretation achieved in bottom-up processing?
- What about the strict competence hypothesis in this approach?

Summary

- **Incremental Interpretation and Rule-to-Rule assumption**
  - need syntactic structure before we can achieve semantic interpretation
  - otherwise need additional machinery to inspect internal state of parser (Shieber & Johnson)
- **Strict Competence Hypothesis**
  - Why would we want it: simplest possible relationship between competence grammar and processor, and between syntax and semantics.
  - Problem: paradox of simultaneous incremental interpretation, strict competence and right-branching structures
- **Solutions to Paradox**
  - less strict version of competence hypothesis
  - or constructing semantics without syntactic relationships

Summary

Parsing Processes:

	reasons pro:	reasons contra:
top-down	– syntax connected, so can achieve semantic interpretation	– left recursion problem – can't explain center-embedding – large degree of ambiguity
bottom-up	– no recursion problem – less ambiguity	– either syntax unconnected or need left-branching constituents – can't explain center-embedding
left-corner	– explains center embedding – syntax connected	– left recursion still a problem – more ambiguous than bottom-up

Outlook

Next week:

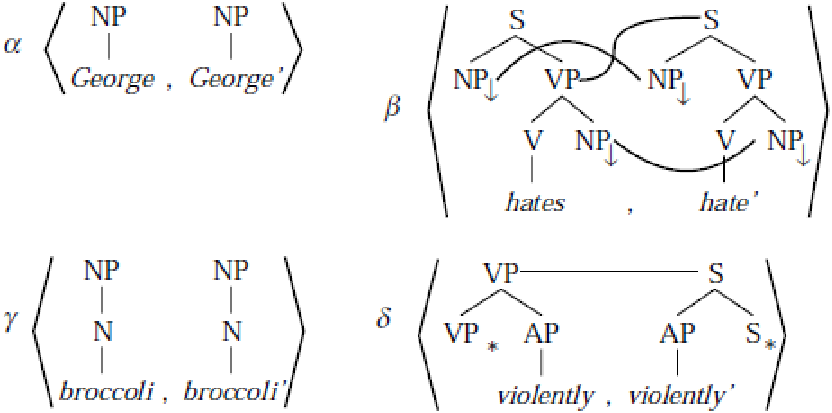
- Experimental evidence for incremental interpretation, incremental syntax in addition to the “center embedding” argument we’ve seen today

This seminar:

- Formalisms and Algorithms for incremental syntactic parsing
- Incremental Semantics: computability and issues
- Applications: practical impacts of incrementality

Synchronous TAG

synchronous = syntactic and semantic trees are paired



Synchronous TAG

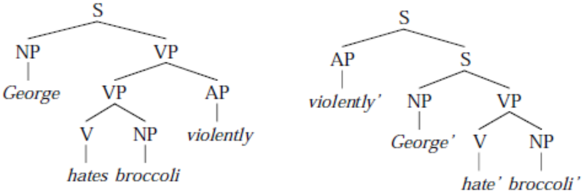


Figure 12: Adjunction to VP at s-structure and corresponding adjunction to S at LF

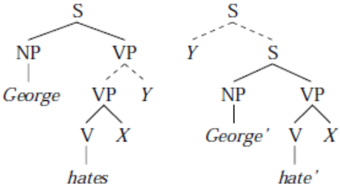


Figure 13: "Partial trees" constructed at the word *hates*