C-Command Relations and Memory Retrieval Mechanisms in Incremental Processing

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What are the primitives of linguistic representations?
The Role of Experiments

1. What role do primitives play in “offline” grammaticality judgments?

2. Do grammatical constraints constrain incremental processing steps?
   - Is grammar a ‘late filter’ on the output of processing? (cf. Townsend & Bever (2001))

3. How do we encode grammatical information within a particular cognitive architecture?
Language and Memory

• **Encoding:**
  Nature and structure of representations, the ‘units’ that representations are built of.

• **Retrieval:**
  Mechanisms and information that guide access to stored representations in memory.
A Case Study: C-command

• C-command is a well-established relation in formal grammars. Used in descriptions of:
  – Binding Phenomena,
  – Scopal Relations,
  – Dependency creation mechanisms (movement, Agree),
  – etc.
C-command

The men [that liked the women] admired themselves.
The woman [that liked the men] admired themselves.

No butler [that the boys insulted] admitted that the jokes bothered him.
The boys [that no butler could stand] admitted that the jokes bothered him.
Principle A:
An anaphor must be co-indexed with a c-commanding phrase in its local domain.

(e.g. Chomsky 1981; Sportiche 2013)

Bound Anaphor Condition:
Quantified NPs … can have anaphoric relations only with pronouns in their c-command syntactic domain.

(Reinhart 1983, although see Barker 2012)
C-command Questions

Encoding:
How are c-command relations represented in memory?

Retrieval:
Do c-command relations guide retrieval of items from memory during incremental dependency creation?

Test Case: Antecedent Retrieval

No butler [that every boy insulted] admitted it bothered him.
The Roadmap

• Reasons to expect that c-command constraints wouldn’t govern antecedent retrieval.
  – Some constraints aren’t always respected.
  – The memory architecture imposes limitations

• Cases of surprising fidelity to c-command constraints.
  – Principle A
  – Bound Variable Pronouns
  – Strong Crossover

• Explore how to reconcile observed behavior with the structure of memory.
Agreement Attraction

The key [to the cabinet] apparently was rusty from disuse.
The key [to the cabinets] apparently was rusty from disuse.

*The key [to the cabinet] apparently were rusty from disuse.
*The key [to the cabinets] apparently were rusty from disuse.
The key [to the cabinet]...were ...

The key [to the cabinets]...were ...

- **Intrusion:**
  When an ungrammatical feature-matching phrase influences the processing of a dependency.

- Intrusion eases the processing of ungrammatical dependencies.

Wagers, Lau & Phillips (2009)
Intrusion/Interference

**Agreement Attraction:**
(Kimball & Aissen 1971; Bock & Miller 1991; Pearlmutter, Garnsey & Bock 1999; den Dikken 2001; Staub 2009; Wagers, Lau & Phillips; Dillon et al. 2013, among others)

**NPI Licensing:**

**Case Licensing:**
(Bader & Beyer 2006; Sloggett 2013)
Content-Addressable Memory

(McElree 2000; McElree, Foraker & Dyer 2003; Lewis & Vasishth, 2005; Lewis, Vasishth & Van Dyke 2006)
Retrieval Via Feature-Match

- Retrieval is *cue-based*: it specifies which features a target should have.

- Probability of retrieving an item $X$ is proportional to the number of the retrieval cues $X$ matches.

- Features are one-place predicates, “inherent” properties of individual chunks in memory representation.

- **Inventory of features**: Morphological (number, gender); Grammatical Role ([subject], [object]), Sister-of: $X$
C-command is not Content

- In order for c-command to be used as a cue, there would need to be a [C-commands: X] feature.

- C-command relations are *not* part of the content of individual items in memory.

- Encoding such features is too computationally costly to be viable.

(feel free to ask me to elaborate in the question period)
The key [to the cabinet] apparently **was** rusty from disuse.

The key [to the cabinet] apparently **were** rusty from disuse.

The key [to the cabinets] apparently **were** rusty from disuse.
C-command Questions

**Encoding:**
How are c-command relations represented in memory?

Architecture: “They may not be. Or not in any straightforward way.”

**Retrieval:**
Do c-command relations guide retrieval of items from memory during incremental dependency creation?

Architecture: “They shouldn’t.”

**Predictions:**

- Antecedent retrieval won’t distinguish c-commanding from non-commanding NPs.
- Antecedent retrieval for c-command sensitive anaphoric dependencies should exhibit Intrusion effects.
Local Anaphor Licensing

The lawyers [that interrogated the defendant] [that interrogated the defendants] yelled at one another ...

The lawyer [that interrogated the defendant] [that interrogated the defendants] yelled at one another ...

PRINCIPLE A: IF INTRUSION:
Self-paced Reading

This -- -- ------- --------.

This -- -- ------- --------.
Self-paced Reading

---- is -- ------- --------.
Self-paced Reading

---- -- an ------ ---------.
Self-paced Reading

---- -- -- example -------.
Self-paced Reading

---- -- -- -- ------- sentence.
English Reciprocals

Post-Reciprocal Reading Times
N=36

ns
English Reflexive Licensing

Sturt (2003), Expt 1
English Reflexives
First Pass Times

Dillon et al. (2013)
English Reflexives
First Pass Times

(also Nicol & Swinney 1989; Badecker & Straub 1992; Xiang et al. 20009; Patil et al. 2009)
Hindi Reciprocals

- Is lack of intrusion in previous studies due to knowledge of verbal argument structure? (all anaphors followed V) (as noted by King et al. 2012)
- If so, pre-verbal reciprocals should exhibit intrusion.
- Hindi reciprocals are pre-verbal and respect Principle A (e.g., Dayal 1994).
Local Anaphors

• **Time Course Evidence:**
  Principle A governs antecedent retrieval online.
  • No Intrusion effects from non-commanding NPs.

• **Implementation/Encoding C-command Question:**
  • Does Local Anaphor Resolution require c-command
  • Local anaphors could just retrieve ‘clause-mates’
  • [clause] is easy to encode, use in cue-based retrieval.

The lawyer(s)_{clause:1} [that liked the crooks_{clause:2}] yelled at **each other**_{clause:1}
Unbounded Constraints

• Unbounded Constraints offer a ‘pure’ test of c-command sensitivity, without complications of ‘domain’.

• **Bound Anaphor Condition:**
  Quantified NPs … can have anaphoric relations only with pronouns in their c-command syntactic domain. (Reinhart 1983)

  • No janitor thinks Mary likes him.
  • No janitor thinks Mary said Sue believes Jill likes him.
1. Bound Variable Experiment 1:
   • Are c-commanding QPs distinguished from non-c-commanding QPs?

2. Bound Variable Experiment 2:
   • Do non c-commanding QPs intrude at all?
Confounding Covariation

**Donkey Anaphora:**
Every farmer who loves a donkey spoils it.

(Heim 1982; Elbourne 2005, 2008; a.o.)

**Telescoping:**
Every British soldier took a rifle. He aimed, then fired.

(Roberts 1989; Poesio & Zucchi 1992; Andersen 2011)
Variable Binding
Experiment 1

Does Retrieval distinguish QP c-commanders from QP non-c-commanders?
Quantificational Manipulation

Kathi didn’t think that …

any janitor liked his job …
Kathi didn’t think that any janitor liked his job when he had to clean up but when he had to clean up ...
C-command Sentences

... 

... 

CP

C

that

dp

the janitor

S

VP

when

V

liked

DP

his job

he had to...
If retrieval distinguishes QPs by c-command:

- Pronoun more difficult when QP does not c-command, easier when QP c-command pronoun.

- Non-c-commanded pronoun will lack antecedent in the sentence → processing difficulty.

(e.g., Greene, Gerrig, McKoon & Ratcliff 1994)
Comparison: Coreference

Kathi didn’t think that …

the janitor liked his job when he had to clean…

but
Difference between QP conditions is reliable, but small. Overall ratings of Quant-NoComm condition is unexpectedly high.

Quantificational p < .05; C-command p < .10
Quantificational * C-command p < .05
Probing Interpretations

• Forced-choice task.

• Participants chose best ‘paraphrases’ of test sentences.

• Two options given:
  • Quantificational Reading
  • ‘Single-Individual’ Reading
BV1: Forced Choice

Kathi didn’t think any janitor enjoyed his custodial duties when he had to clean up messes left after prom.

1. Every janitor disliked having to clean up after prom.

2. There was someone who disliked having to clean up after prom.
BV1: Forced Choice

Kathi didn’t think any janitor enjoyed performing his custodial duties, but he had to clean up the messes left after prom anyway.

1. There was someone who had to clean up after prom.

2. Every janitor had to clean up after prom.
Participants reliably reject interpretations that require co-variation between a QP and a pronoun it doesn’t c-command.

Participants choose bound readings when the QP c-commands the pronoun.

Quantificational p < .001; C-command p < .001
Quantificational * C-command p < .001
BV1: Eye-tracking

...but he had to clean up...
BV1: Eye-tracking

...but he had to clean up...

Rightbound Times:

The sum of time first spent in a region before a participant moves on.
Bound Variable Expt. 1, N=42
Post-pronoun Rightbound Reading Times

Bound Variable Expt. 1, N=42
Post-pronoun Rightbound Reading Times
BV1: Summary

- Participants display offline sensitivity to the c-command constraint on BV pronouns in a *forced choice* interpretation task.
- During incremental processing participants immediately distinguish QPs based on their c-command relation with a pronoun.
Variable Binding
Experiment 2

Do non-c-commanding QPs intrude on antecedent retrieval at all?
BV2: Interference

The leaders scolded her... after the incident
no girl scout
no boy scout
If retrieval ignores non-commanding QPs:

If non-commanding QPs intrude:
Coreference

S

DP

D

the

N

leaders

NP

that

CP

the girl scout ✔

the boy scout ✗

VP

V

scolded

DP

her
Participants choose the feature-matching DP as the referent of the pronoun when possible. Results in higher acceptability overall.
Bound Variable Expt. 2, N=30
Rightbound Reading Times, Pronoun

Quant Match
Quant NoMatch
Ref Match
Ref NoMatch
Variable Binding Summary

• **Offline Judgments:**
  Experimental verification that naïve participants display sensitivity to c-command constraint on BV pronouns.

• **Time Course:**
  Antecedent retrieval immediately respects the c-command constraint on BV pronouns.
Strong Crossover

Which man did he think that Mary liked ____?

A pronoun can’t be bound by a moved wh-phrase whose base position it c-commands.

(Postal 1971; Wasow 1972; Chomsky 1981, among others)
Kathi asked …

*it seemed* that *he* spoke with ____ …

**which man**

**which woman**

____ had said that *he* spoke with Sue…
If participants are sensitive to Crossover:

Acceptability Ratings:

Reading Times:

If participants don’t respect Crossover:

Acceptability Ratings:

Reading Times:
Strong Crossover, N=12
7pt. Acceptability Judgments

Crossover < .001; Match p < .01
Crossover* Gender-Match p < .001
### NoCrossover Sentences

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### Crossover Sentences

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Strong Crossover
Post-Pronoun Reading Times

- Cross Match
- Cross NoMatch
- NoCross Match
- NoCross NoMatch
Is it really c-command?

- **Hypothesis:**
  
  Un-integrated fillers are ignored by antecedent retrieval.

(Shan & Barker, 2006)
Weak Crossover

Which man did his mom think that Mary liked ___?

The pronoun does not c-command the gap site.

• His mom thought that Mary liked John.
Kathi asked ...

which man _____ had said that [his supervisor]

which woman _____

spoke with Sue.

(Postal 1971; Wasow 1972; Chomsky 1981)
Crossover

Kathi asked ...

which man it seemed that [his supervisor]
which woman spoke with ____.

(Postal 1971; Wasow 1972; Chomsky 1981)
Weak Crossover, N=16
7pt. Acceptability Judgments
Jane asked which X it seemed that his supervisor had already spoken with regarding the food-fight in the cafe...
Crossover: Conclusion

- Retrieval respects Strong Crossover.
- Retrieval does not respect Weak Crossover.
- Strong Crossover effects not primarily driven by unintegrated status of wh-filler.
- Strong Crossover sensitivity tracks c-command status of the pronoun and gap.
• **Time Course:**
  Distinctions made by c-command constraints govern immediate incremental processing mechanisms like antecedent retrieval (BV pronoun licensing, Strong Crossover).

  Constraints based on other information, e.g. linear order, do not influence retrieval (Weak Crossover).
• **How are constraints implemented?:**

This is a genuine puzzle/challenge.

The memory architecture that makes c-command difficult is well-motivated.

But nevertheless, it appears that memory retrieval rapidly makes distinctions that track c-command.
Options for Reconciliation

1. Propose a different search mechanism within the same architecture.

2. Find a feature-based ‘analogue of c-command’
Option 1: Serial Search

S

D

the

DP

N

leaders

NP

that

CP

no girl scout

VP

V

scolded

DP

her

...
Serial Search: Prediction

- Retrieval time should increase as a function of distance between anaphor and antecedent.

  (Sternberg 1966; Knuth 1967; McElree & Dosher 1989)

- Test:
  (1) No butler thought that Mary liked him.
  (2) No butler thought that Jill said that Mary liked him.
Speed-Accuracy Tradeoff

- Method that offers distinct measures of the time it takes to retrieve an item, and accuracy of interpretation.

(e.g. Wickelgren 1977)
Option 2: Proxy Strategies

- Is there a strategy that can encode the relevant distinctions without requiring retrieval to appeal directly to c-command?
Implementing BV Sensitivity

A QP should be syntactically active only so long as the parser is currently building structure in its scope.
Pro-active Representation Management

• Pre-emptively make QPs ‘inert’ for retrieval once the edge of their scope domain has been reached.

• A number of ways to make things inert:
  
  • Delete retrieval cues
    (Kush 2013)
  
  • Remove from ‘working memory’
    (Ecker, Lewandowsky & Oberauer 2013)
Spines

• Define a spine as a right-branching series of nodes.

• Encode spine feature on every QP. (Like [clause], a [spine] feature is easily coded as content.)

• **Bound Anaphor Condition** (incremental): A pronoun encountered in left-to-right processing can be bound by a QP if the parser has not yet completed the spine to which the QP is attached.
The troops scolded her…
Predictions

- If antecedent retrieval is required before QP-removal operations are triggered, intrusion is expected.
- Need a pronoun that can occur before QP removal.
- Pre-verbal clitics may fit the bill.

The woman [that the man spoke to ] le/lo ...
The woman [that no man spoke to ] le/lo ...
Wrap Up

• Within a content-addressable memory architecture, c-command relations cannot guide direct-access retrieval.

• Antecedent retrieval during incremental processing respects distinctions made by formal c-command constraints.

• Still lots of work to be done to figure out how to encode and implement faithfulness to grammatical constraints while holding the memory architecture constant.
  • Different access procedure?
  • Proxy strategies?
  • …?
Thanks!
Precede and Command

• Can proxy strategies provide insight into the best formal analysis of anaphoric constraints?

• The implementation of the BAC approximates \textit{precede-and-command} restrictions.

  (Langacker 1969; Jackendoff 1972; Lasnik 1976)

• \textit{Precedence} tracks L-to-R parsing.

• Command is closer to ‘phase command’, not c-command per se.

  (Bruening 2013)
Binding w/o Surface C-command

Binding from spec, DP:

• Nobody’s mother though Mary hated him.

Inverse Linking:

• Someone from every city hates it.

Binding from VP:

• We’ll drink no wine before its time.

(May 1977; Buering 2003; Barker 2012, a.o.)
These examples show that surface c-command isn’t necessary for QP-pronoun binding.

Suppose c-command at LF is necessary. (May 1977, Kush 2013, others)

Can we encode LF-command using spines?
LF Command

- Redefine a **spine** as a series of right-branching phrases that constitute a clause.

- [Nobody[spine:1]’s mother][spine:1] …

- [Someone from every city][spine:1] [spine:1] …