Decay and interference in human sentence processing

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1. Main claims

- We can derive computationally explicit & empirically adequate sentence processing models from very general principles of STM/WM uncovered in cognitive psychology

- Many of those principles are captured by ACT-R: Everything just falls out of ACT-R's **spreading activation** (similarity-based interference) and **base-level learning** (decay and re-activation) mechanisms.

2. Existing theories of sentence processing

- In psycholinguistics, there is no **domain-independent** theory about how momentarily buffered structures are brought into contact with incoming words.

- It is simply assumed that they are:

  - Existing complexity metrics are predicated over **highly domain-specific** conditions (Discourse Locality Theory (Gibson 2000), Early Immediate Constituents (Hawkins 2003)).

  - Parsing architectures typically provide a limited capacity buffer, with structures assumed to be available if they are present, not if they are not (e.g., Crocker and Brants 2001).

  - Locality and decay are sometimes appealed to as *ad hoc* explanatory principles (Stevenson; Kempen and Vosse; Tabor).

3. The parsing model

Main claims

Existing theories of . . .

The parsing model
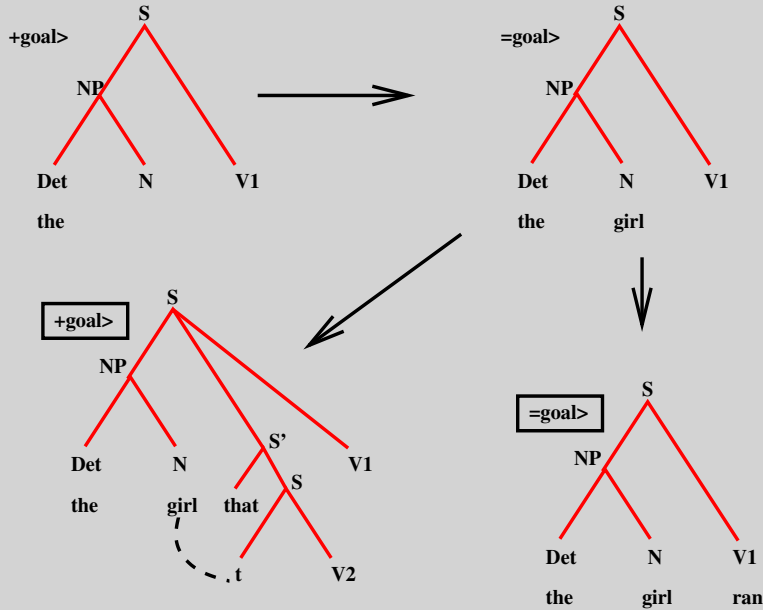
Some evidence . . .

Evidence for goal . . .

Decay and . . .

Summary, open . . .

Figure 1: Simple illustration of left corner (shift-reduce) parsing (cf. purely top-down LL(1) parsing)

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ACT-R's activation decay and interference mechanisms are the key explanatory mechanisms:

- **Decay of arguments**: arguments are retrieved at verbs subcategorizing for them. The arguments' activation decay determines retrieval difficulty at verb, and therefore the reading time at the verb.

- **Decay of predicted structures**:

  - TOP-DOWN PREDICTION: Predict (new) sentence structure when enough information comes in (+goal).

  - GOAL REACTIVATION: Each creation of a hypothesized structure (a +goal) increases its activation and affects reading time (implemented by carrying out a retrieval-and-harvest).

- **Similarity-based interference** during retrieval.

3.1. Example: The English subject/object relatives

(1)   a. **Subject relative**
The _reporter_ who _sent_ the photographer to the editor hoped for a good story.

       b. **Object relative**
The _reporter_ who the photographer _sent_ to the editor hoped for a good story.

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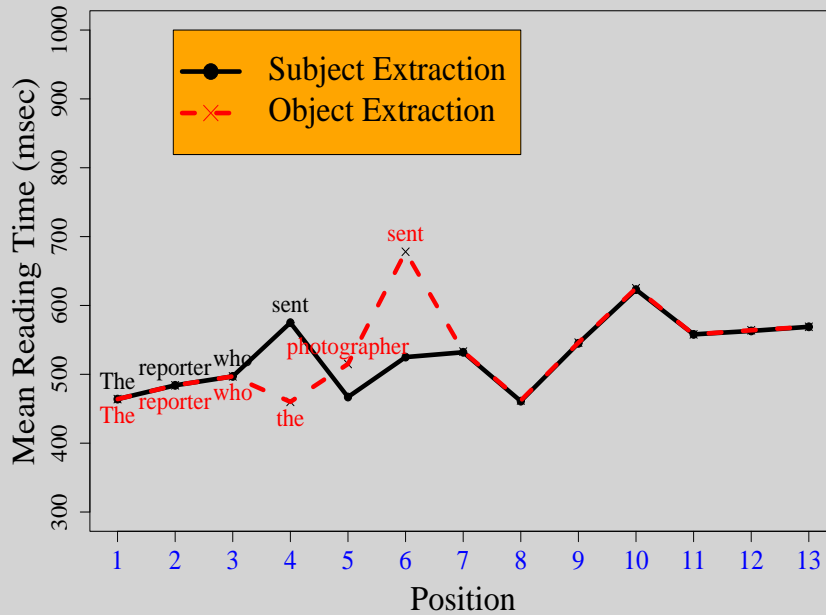
Summary, open . . .

Figure 2: Model's behavior with English subject-object relatives. **d=0.5**
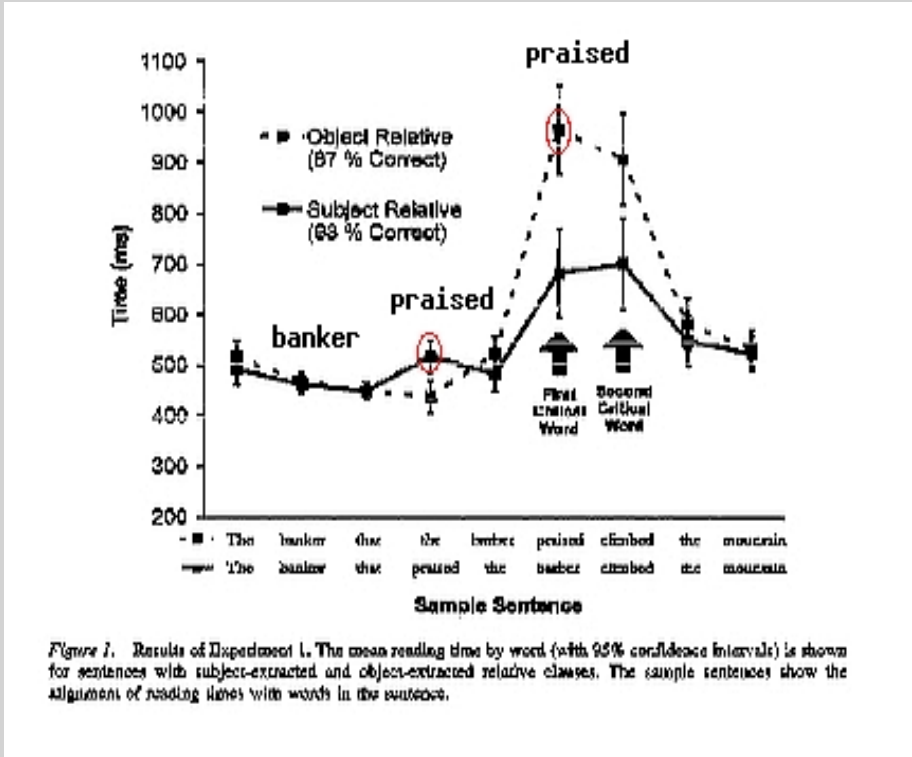
Figure 3: Gordon et al 2001 (JEP)

4. Some evidence for decay and interference

Methodology: Noncumulative moving window, within-subjects design with stimuli counterbalanced across conditions.

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5. Evidence for goal reactivation

(2) a. **Nothing intervening**

Siitaa-ne Hari-ko Ravi-ko [kitaab-ko
Sita-erg Hari-dat Ravi-dat book-acc
khariid-neko] bol-neko kahaa
buy-inf   tell-inf   told
'Sita told Hari to tell Ravi to buy the book.'

b. **Adverb intervening**

Siitaa-ne Hari-ko Ravi-ko [kitaab-ko
Sita-erg Hari-dat Ravi-dat book-acc
jitnii-jaldii-ho-sake khariid-neko] bol-neko kahaa
as-soon-as-possible   buy-inf   tell-inf   told
'Sita told Hari to tell Ravi to buy the book as soon
as possible.'

c. **Verb-modifying PP intervening**

Siitaa-ne Hari-ko Ravi-ko [kitaab-ko
Sita-erg Hari-dat Ravi-dat book-acc
ek baḍhiya dukaan se khariid-neko] bol-neko
from-a-good-shop   buy-inf   tell-inf
kahaa
told

'Sita told Hari to tell Ravi to buy the book from a good shop.'

d. **NP-modifying relative clause intervening**

Siitaa-ne Hari-ko Ravi-ko [kitaab-ko
Sita-erg Hari-dat Ravi-dat book-acc
jo-mez-par-thii   khariid-neko] bol-neko kahaa
that-was-on-a-table buy-inf   tell-inf   told

'Sita told Hari to tell Ravi to buy the book that was lying on a/the table.'

Figure 4: Double embedding, nothing intervenes

Figure 5: Double embedding, verb-modifying adjunct intervenes
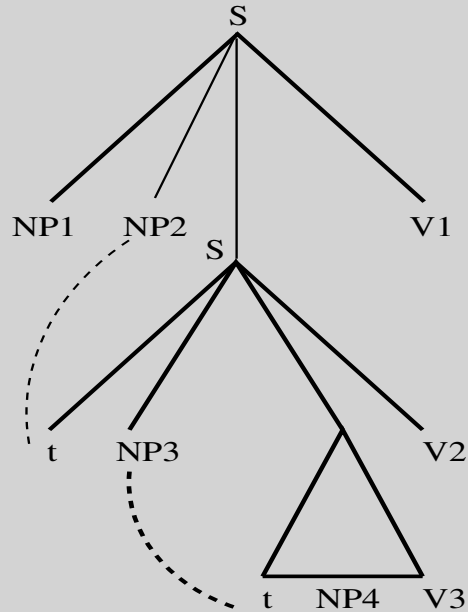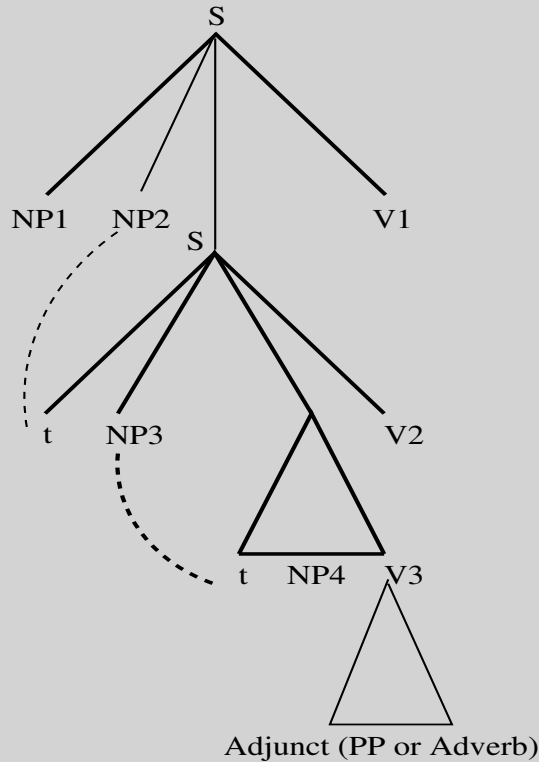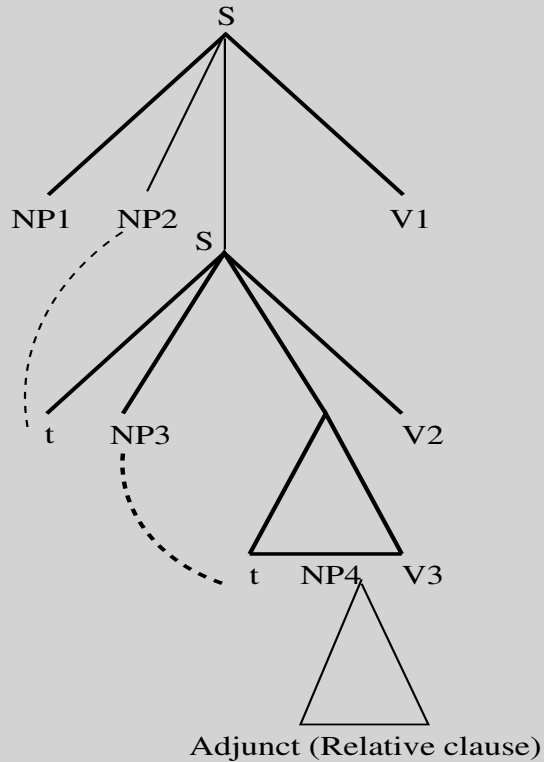
Main claims

Existing theories of. . .

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Figure 6: Double embedding, NP-modifying adjunct intervenes
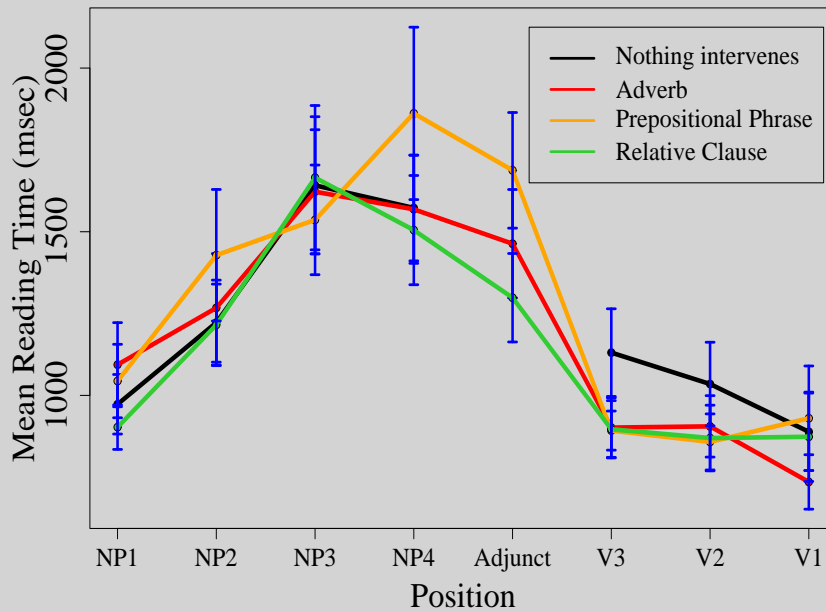
Figure 7: Hindi Experiment 1; mean reading time for all four conditions, with 95% confidence intervals.

Main claims

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Summary, open . . .

5.1. Modeling individual variation

(3) a. **Nothing intervening**

Siitaa-ne Hari-ko Ravi-ko [kitaab-ko
Sita-erg Hari-dat Ravi-dat book-acc
khariid-neko] bol-neko kahaa
buy-inf   tell-inf   told
'Sita told Hari to tell Ravi to buy the book.'

b. **Adverb intervening**

Siitaa-ne Hari-ko Ravi-ko [kitaab-ko
Sita-erg Hari-dat Ravi-dat book-acc
jitnii-jaldii-ho-sake khariid-neko] bol-neko kahaa
as-soon-as-possible   buy-inf   tell-inf   told
'Sita told Hari to tell Ravi to buy the book as soon
as possible.'

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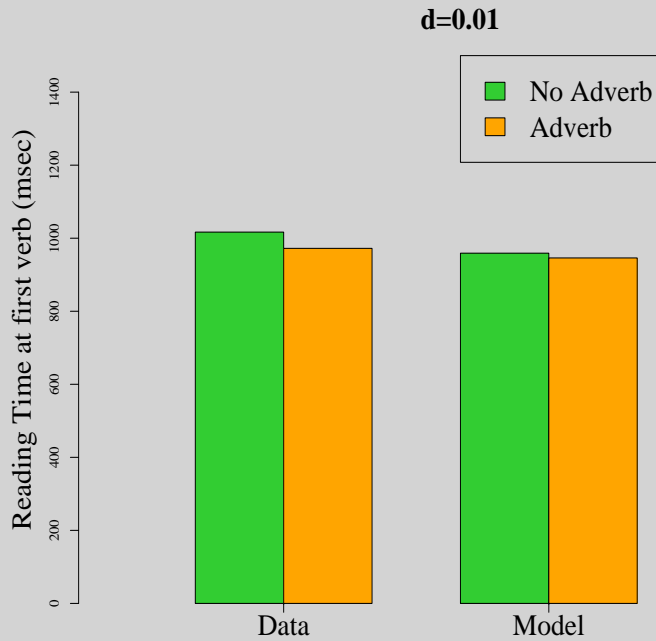
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Figure 8: Hindi Experiment 2

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Figure 9: Hindi Experiment 2
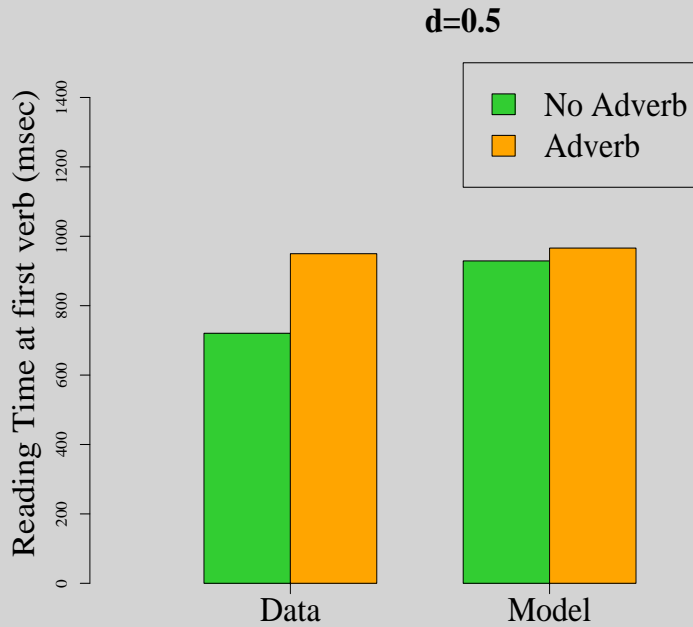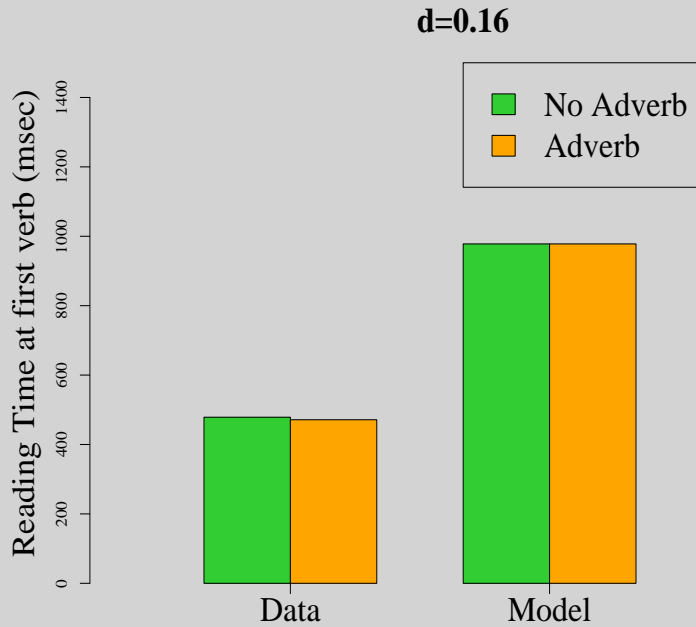
Figure 10: Hindi Experiment 2

Main claims

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6. Decay and interference are separate factors

Van Dyke and Lewis (in press, JML), 30 second summary

(4)   a. **Reanalysis very difficult**
      While Mary read the book she ordered from Amazon arrived.

   b. **Reanalysis relatively easy**
      The secretary forgot the student who was waiting for the exam was standing in the hallway.

   c. **Attachment, non-interfering**
      The secretary *forgot that* the student who was waiting for the exam *was standing* in the hallway.

   d. **Attachment, interfering**
      The secretary *forgot that* the student who *knew that* the exam was important *was standing* in the hallway.

There is evidence from fMRI research that Reanalysis and Attachment are distinct processes (Vannest and Lewis, in preparation).
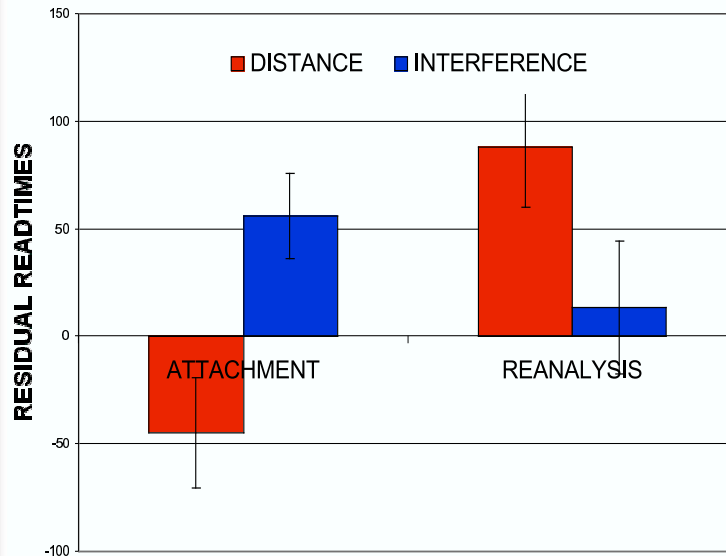
Figure 11: Van Dyke and Lewis results

Main claims

Existing theories of. . .

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6.1. Independent evidence for decay vs. interference dichotomy: Two Hindi experiments

(5) a. **Object relative, no extra DRs**

vo-kaagaz   jisko   us-laḍke-ne   dekhaa
that-**paper** which that-**boy**-erg saw
bahut-puraanaa thaa
very-old   was
'That paper which that boy saw was very old.'

b. **Object relative, two extra DRs**

vo-kaagaz jisko us-laḍke-ne **mez ke-piiche**
that-paper which that-boy-erg *table behind*
gire-hue dekhaa bahut-puraanaa thaa
fallen   saw   very-old   was
'That paper which that boy saw *fallen behind a/the table* was very old.'

Main claims

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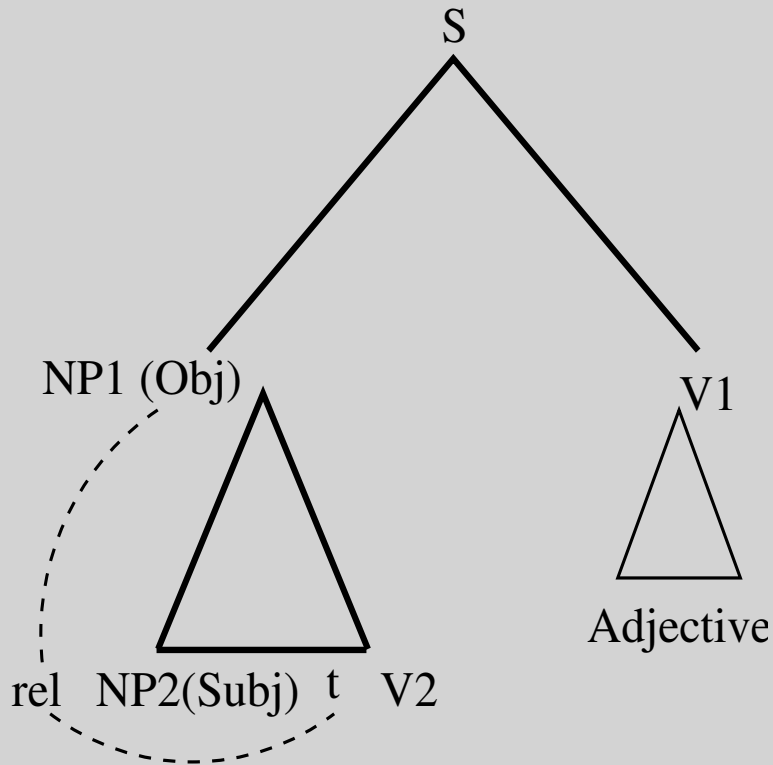
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c. **Subject relative, no extra DRs**

vo-laḍkaa jisne us-kaagaz-ko   dekhaa
that-boy   who that-paper-acc saw
bahut-jigyaasu thaa
very-inquisitive was

'That boy who saw that (piece of) paper was very inquisitive.'

d. **Subject relative, two extra DRs**

vo-laḍkaa jisne us-kaagaz-ko   **mez ke-piiche**
that-boy   who that-paper-acc *table behind*
gire-hue dekhaa bahut-jigyaasu thaa
fallen   saw   very-inquisitive was

'That boy who saw that (piece of) paper *fallen behind a/the table* was very inquisitive.'

Figure 12: Object relatives, no intervening discourse referents
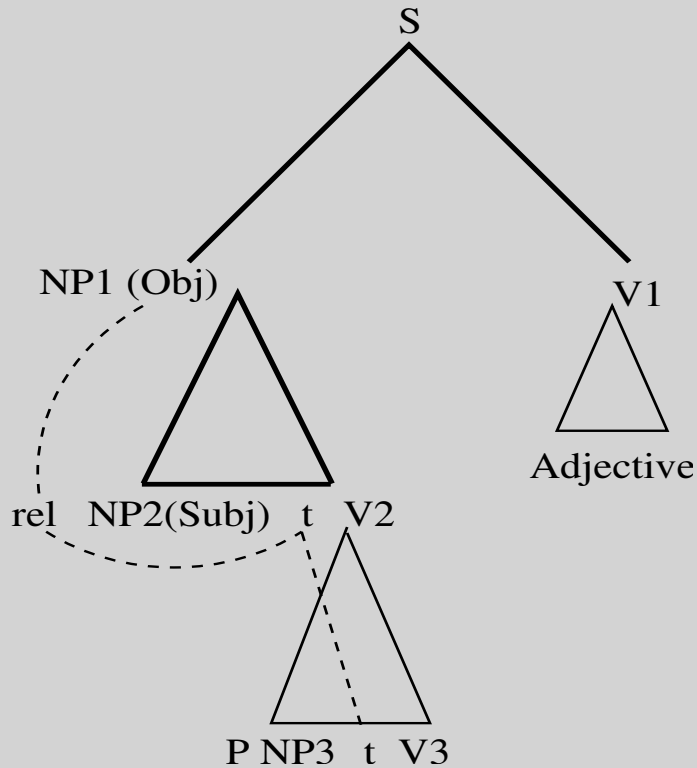
Figure 13: Object relatives, two intervening discourse referents (goal reactivation)

Main claims

Existing theories of . . .

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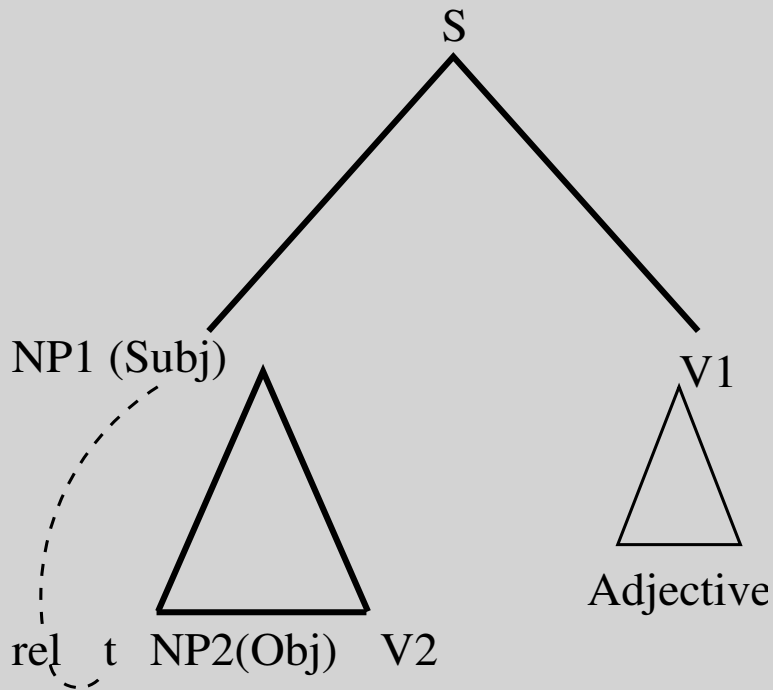
Summary, open . . .

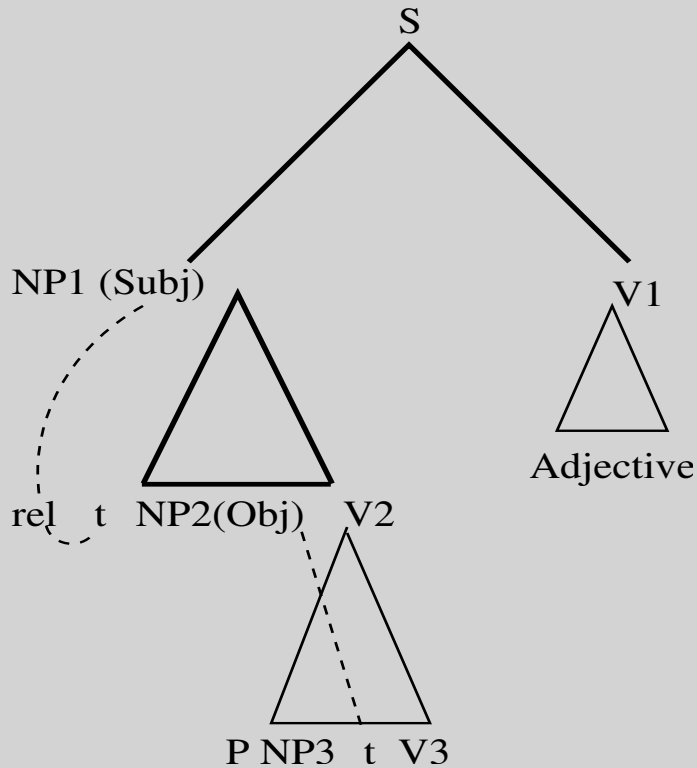Figure 14: Subject relatives, no intervening discourse referents

Figure 15: Subject relatives, two intervening discourse referents (goal reactivation)

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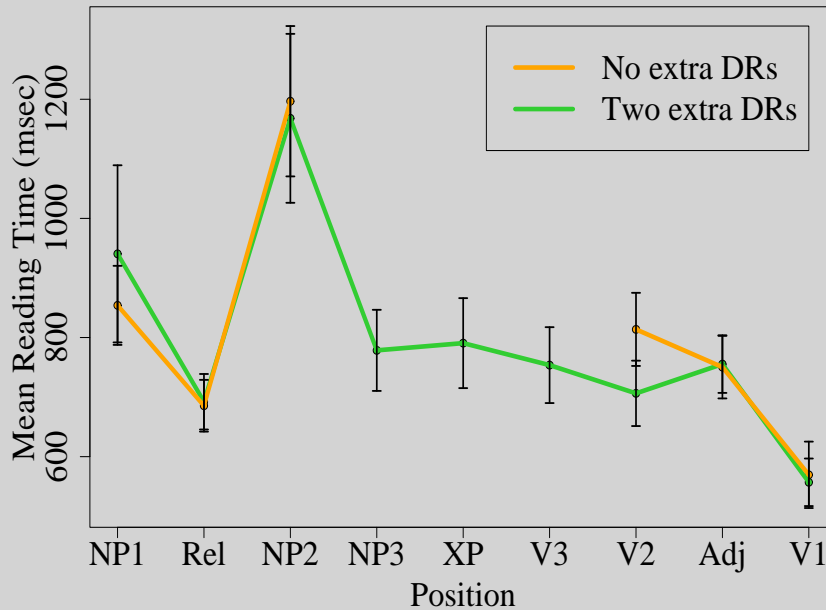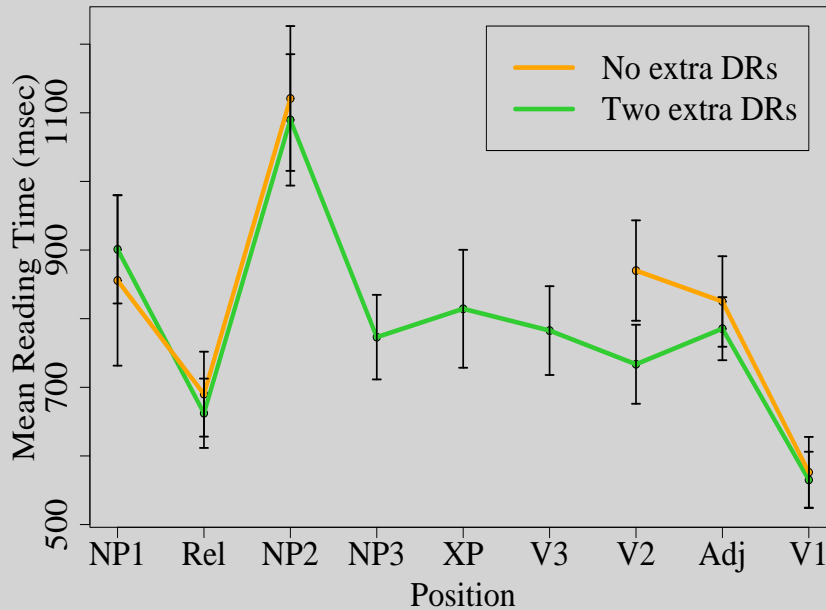
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Figure 16: Object relatives (with 95% confidence intervals)

Main claims

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Figure 17: Subject relatives (with 95% confidence intervals)

6.2. Playing off harmful effect of increased similarity-based interference against facilitation due to goal reactivation

(6)   a. **Object relative, no extra DRs**

vo-dukaandaar   jisko   us-laḍke-ne   dekhaa
that-**shopkeeper** whom that-**boy**-erg saw
bahut-amiir thaa
very-rich   was
'That shopkeeper whom that boy saw was very rich.'

b. **Object relative, two extra DRs**

vo-dukaandaar jisko us-laḍke-ne **mez**
that-shopkeeper whom that-boy-erg table
ke-saamne khaḍe-hue dekhaa bahut-amiir thaa
in-front-of   standing   saw   very-rich   was
'That shopkeeper whom that boy saw standing in front of a/the table was very rich.'

c. **Subject relative, no extra DRs**

vo-laḍkaa jisne us-dukaandaar-ko   dekhaa
that-boy who that-shopkeeper-acc saw
bahut-jigyaasu thaa
very-inquisitive was

'That boy who saw that shopkeeper was very inquisitive.'

d. **Subject relative, two extra DRs**

vo-laḍkaa jisne us-dukaandaar-ko   **mez**
that-boy who that-shopkeeper-acc table
ke-saamne khaḍe-hue dekhaa bahut-jigyaasu
in-front-of   standing   saw   very-inquisitive
thaa
was

'That boy who saw that shopkeeper standing in front of a/the table was very inquisitive.'

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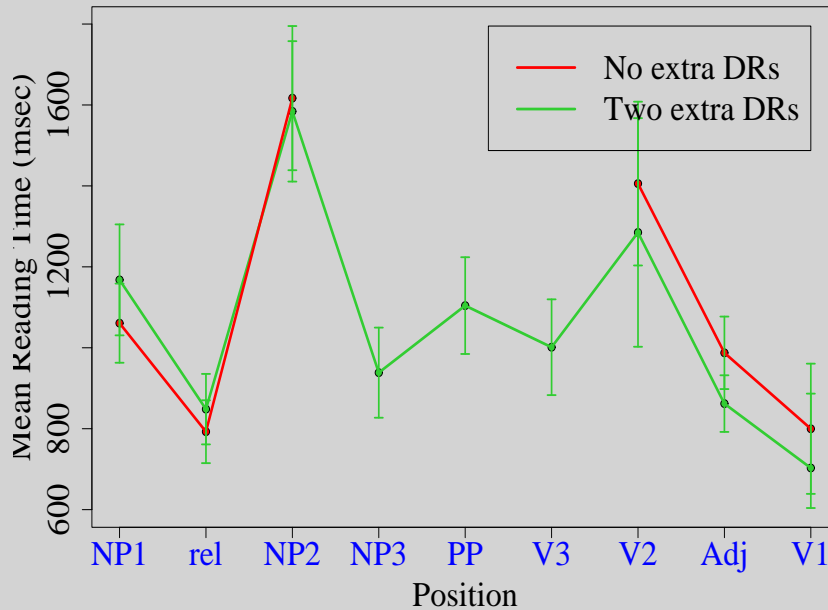Figure 18: Object relatives; mean reading time for each position, with 95% confidence intervals.
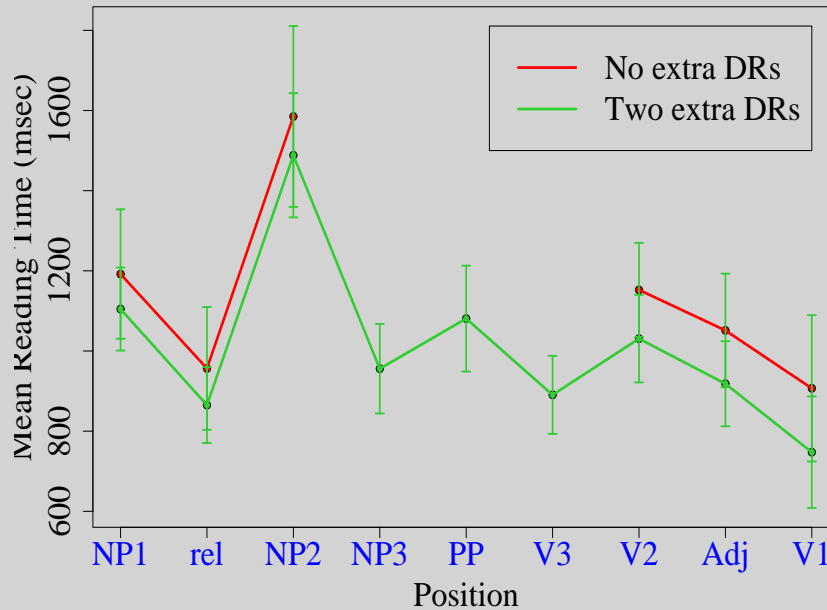
Figure 19: Subject relatives; mean reading time for each position, with 95% confidence intervals.

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Evidence for goal . . .

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Summary, open . . .

7. Summary, open issues, future work

- ACT-R's decay and interference mechanisms can account for some key facts that existing theories of sentence processing cannot. For additional results, see Rick's and Shravan's web pages.

- However, perhaps we need to assume differing decay rates for lexical items versus predicted structures (goals).

- There now exists (English) eyetracking data for relatively large volumes of text, robust large-scale parsers, and syntactically annotated treebanks; it's now possible to go beyond toy grammars. An important test of the ACT-R based theory (and of other theories) will be its ability to account for this larger volume of behavioral data.