

# Sentence Comprehension as a Cognitive Process: A computational modeling approach

## Day 4: Individual differences and scanpaths

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<http://bit.ly/sentcomp>

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## What purpose do regressive eye movements serve in reading?

This question was raised in a classic paper from 1982 (Frazier and Rayner). Consider the sentence:

- (1) Although Mary forgot her husband **didn't** seem very upset yesterday.

Frazier and Rayner argued that when the parser discovers that an incorrect parse has been built, the eyes move selectively to the ambiguous region (selective reanalysis). Selective reanalysis implies a tight coupling of the eye with parser actions.

# Meseguer et al 2002

M et al investigated the selective reanalysis idea

## High attachment to VP1 (dispreferred)

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*El Profesor* [VP1 *dijo* [CP *que los alumnos*

[VP2 *se levantarán del asiento*]] [AdvP *cuando los directores entraron en la clase.*]]

The teacher [VP1 said [CP that the students

[VP2 had to stand up from their seats]] [AdvP when the directors came INDIC into the room]]

## Low attachment to VP2 (preferred)

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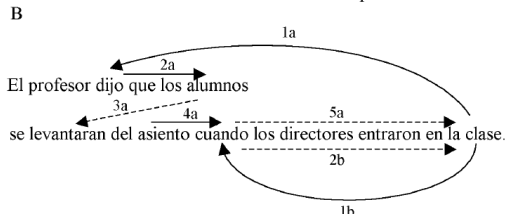
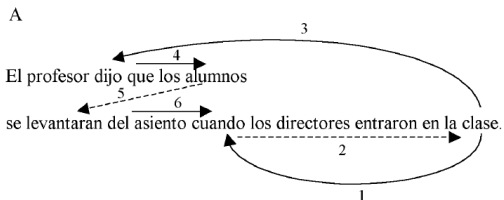
*El Profesor* [VP1 *dijo* [CP *que los alumnos*

[VP2 *se levantarán del asiento* [AdvP *cuando los directores entraran en la clase.*]]]]

The teacher [VP1 said [CP that the students

[VP2 had to stand up from their seats [AdvP when the directors come SUBJ into the room]]]]

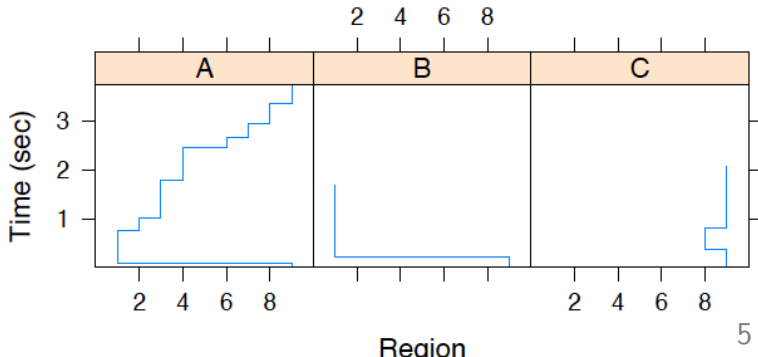
# Meseguer et al 2002



# Scanpaths in reading

von der Malsburg & Vasishth, 2011

Using a method (<http://bit.ly/scasim>) developed by von der Malsburg, three basic scanpath types were found in the Meseguer et al data:



# Scanpaths in reading

Malsburg & Vasishth, 2011

- 1** We extracted scanpath patterns automatically in reading, and showed that re-reading is an important recovery strategy when the parser makes the wrong attachment.
- 2** Another common pattern was a short regression to the preceding word, reminiscent of Time-Outs hypothesized by Don Mitchell.
- 3** The idea that the parser guides the eye to the region where the problem occurred has little support—a more common situation is a somewhat loose eye-parser coupling.

What can scanpaths tell us about parsing strategies? We turn to this issue next.

# Malsburg and Vasishth, Lang. and Cog. Proc. 2012

## Scanpaths reveal syntactic underspecification and reanalysis strategies

- (3) *El profesor dijo que los alumnos se levantarán del asiento ...*  
 The teacher said that the students had to stand up from their seats ...
- a. [AdvC *cuando* los *directores* **entraron** *en la clase de música*].  
 [AdvC when the directors came into the music class].
- b. [AdvC *cuando* los *directores* **entraran** *en la clase de música*].  
 [AdvC when the directors come into the music class].
- c. [AdvC **si** los *directores* *entraban* *en la clase de música*].  
 [AdvC if the directors come into the music class].

# Malsburg and Vasishth, Lang and Cog. Proc. 2013

## Scanpaths reveal syntactic underspecification and reanalysis strategies

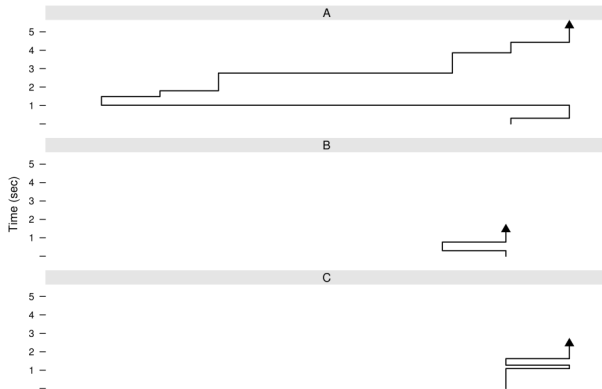
TABLE 1  
The critical regions of the material in (3)

<i>Condition</i>	<i>Head</i>	<i>Pre-verbal</i>	<i>Verb</i>	<i>Spillover</i>
(a)	<i>cuando</i> when	<i>los directores</i> the directors	<i>entraron</i> came (disambiguates, high)	<i>en la clase de ...</i> into the class ...
(b)	<i>cuando</i> when	<i>los directores</i> the directors	<i>entraran</i> come (disambiguates, low)	<i>en la clase de ...</i> into the class ...
(c)	<i>si</i> if (unambiguous, low)	<i>los directores</i> the directors	<i>entraban</i> come	<i>en la clase de ...</i> into the class ...



# Malsburg and Vasishth, Lang and Cog. Proc. 2013

## Scanpaths reveal syntactic underspecification and reanalysis strategies

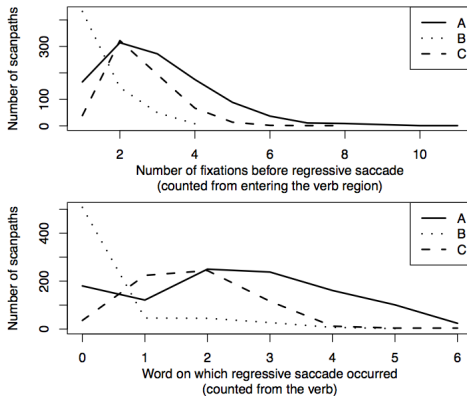


El profesor dijo que los alumnos se levantarán del asiento cuando los directores entraron en la clase ...

**Figure 3.** Prototypes of the three super clusters: rereading of the preceding material (A), rapidly triggered regressions from the verb to the pre-verbal region (B), checking regressions from the spillover region to the verb region (C).

# Malsburg and Vasishth, Lang and Cog. Proc. 2013

## Scanpaths reveal syntactic underspecification and reanalysis strategies

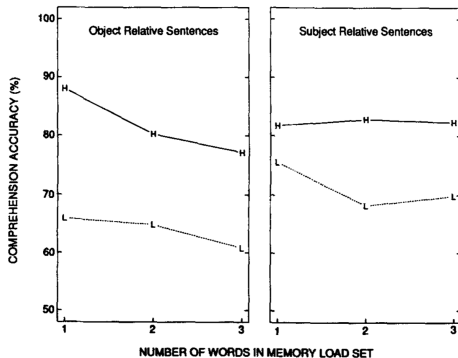


**Figure 8.** Plots showing when and where regressive saccades were executed after the verb region was entered. The first plot shows after how many fixations the first regression occurred. The second plot shows on which word the first regression was launched (0 is the verb in the adverbial clause). In the pattern that we called “rapid regressions” (B), regressions occurred, by definition, early. In the “checking” pattern (revisiting the verb of the adverbial clause, C), regressions occurred later. Regressions in the rereading pattern (A) had the longest delay.

# Malsburg and Vasishth, Lang and Cog. Proc. 2013

## Scanpaths reveal syntactic underspecification and reanalysis strategies

Working memory “capacity” has been implicated in determining sentence comprehension difficulty. An early example is [1].



## Daneman and Carpenter task traditionally used for measuring memory capacity

This is one version of the task:

- Participants are shown groups of sentences to read aloud.
- After reading all sentences, participants have to recall the last word in each sentence.
- Number of sentences in a group are increased from 2 to 6, with three groups of each size.
- Raw scores: *total* number of words recalled in the correct order.

One criticism of this method of measuring working memory “capacity” is that it might reflect reading experience [2].

## Operation span as a measure of working memory “capacity”

See [3].

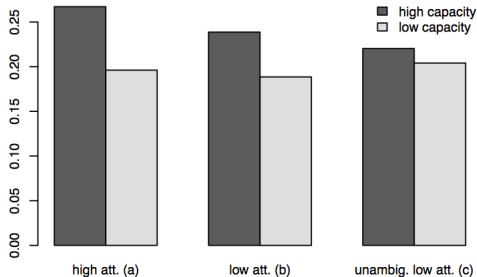
This involves two tasks:

- In the first, the memory task, participants have to memorize words for later recall (sets of 2-5).
- The second is a distracter task that is intended to prevent participants from actively rehearsing the memory items. The distracter task consisted of checking the correctness of simple equations, e.g.,  $(5 - 3) \times 3 = 8$ .

The dependent variable is partial credit unit scores, the mean proportion of correctly recalled items within the sets.

# Malsburg and Vasishth, Lang and Cog. Proc. 2013

## Scanpaths reveal syntactic underspecification and reanalysis strategies



**Figure 7.** The effect of working memory capacity of participants on the rate of rereading in the three conditions. When capacity was low, there was no difference between the conditions. However, when capacity was high, there was an increased rate of rereading in the high-attachment condition compared to the low-attachment conditions suggesting that high-capacity participants processed the attachment more thoroughly. Note that the differences between the two low-attachment conditions were not significant.

# Malsburg and Vasishth, Lang and Cog. Proc. 2013

## Scanpaths reveal syntactic underspecification and reanalysis strategies

An ambiguity advantage in first-pass reading time.

**Table:** In the pre-verbal region, the speedup due to ambiguity was larger for low capacity subjects.

	Ambiguous	Unambiguous	Speedup
High capacity	458	501	-43
Low capacity	431	520	-89

# Malsburg and Vasishth, Lang and Cog. Proc. 2013

## Scanpaths reveal syntactic underspecification and reanalysis strategies

This work shows that

- 1 the eye registers an attachment problem quite late.
- 2 Working memory capacity modulates parsing: under high load, readers may tend to avoid completing the attachment: recall the **ambiguity advantage** from Day 1.
  - 1 Lower re-reading rates for low capacities in high attachment condition.
  - 2 First-pass reading times in the pre-verbal region show an ambiguity advantage.



## In conclusion

- The eye-parser connection seems to be not quite as tight as Just and Carpenter assumed it to be in 1992.
- A computational model of capacity differences inducing underspecification would be very helpful for understanding how capacity interacts with parsing processes.
- Felix will present such a model next.

- [1] Jonathan King and Marcel Adam Just.  
Individual differences in syntactic processing: The role of working memory.  
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- [2] Justine B. Wells, Morten H. Christiansen, David S. Race, Daniel J. Acheson, and Maryellen C. MacDonald.  
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- [3] Andrew RA Conway, Michael J Kane, Michael F Bunting, D Zach Hambrick, Oliver Wilhelm, and Randall W Engle.  
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Psychonomic Bulletin & Review, 12(5):769–786, 2005.

