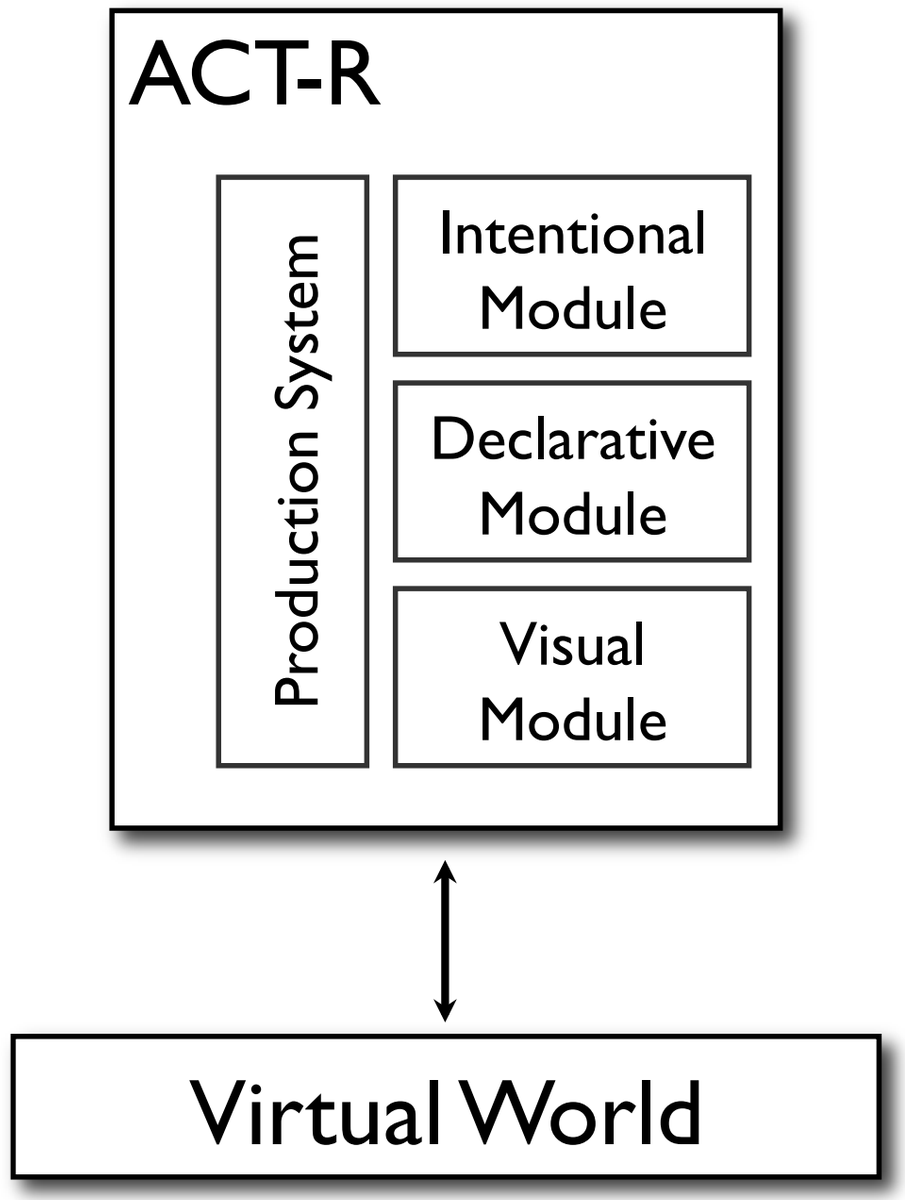
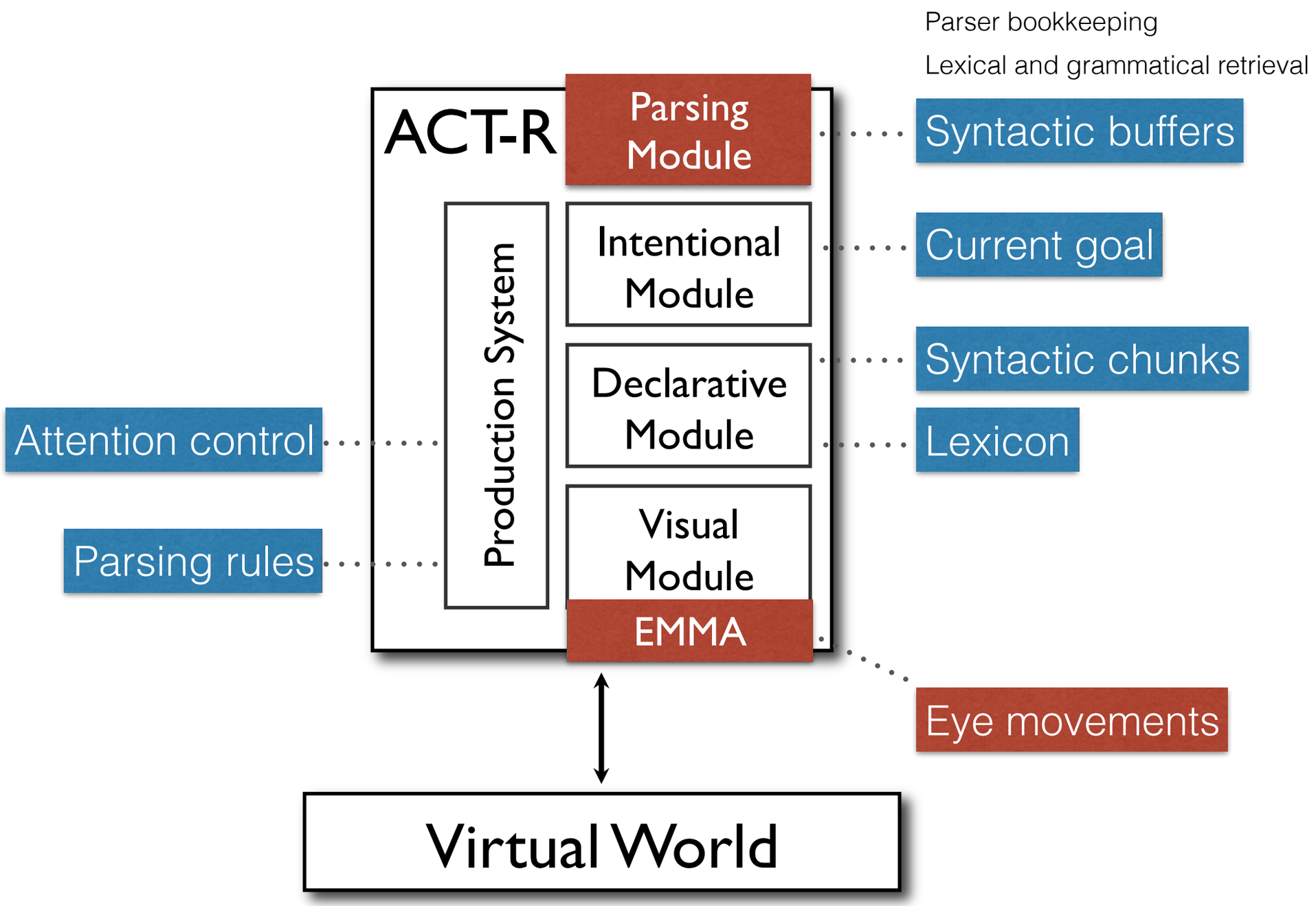
An Integrated Model of Eye Movements in Sentence Comprehension

Model Structure

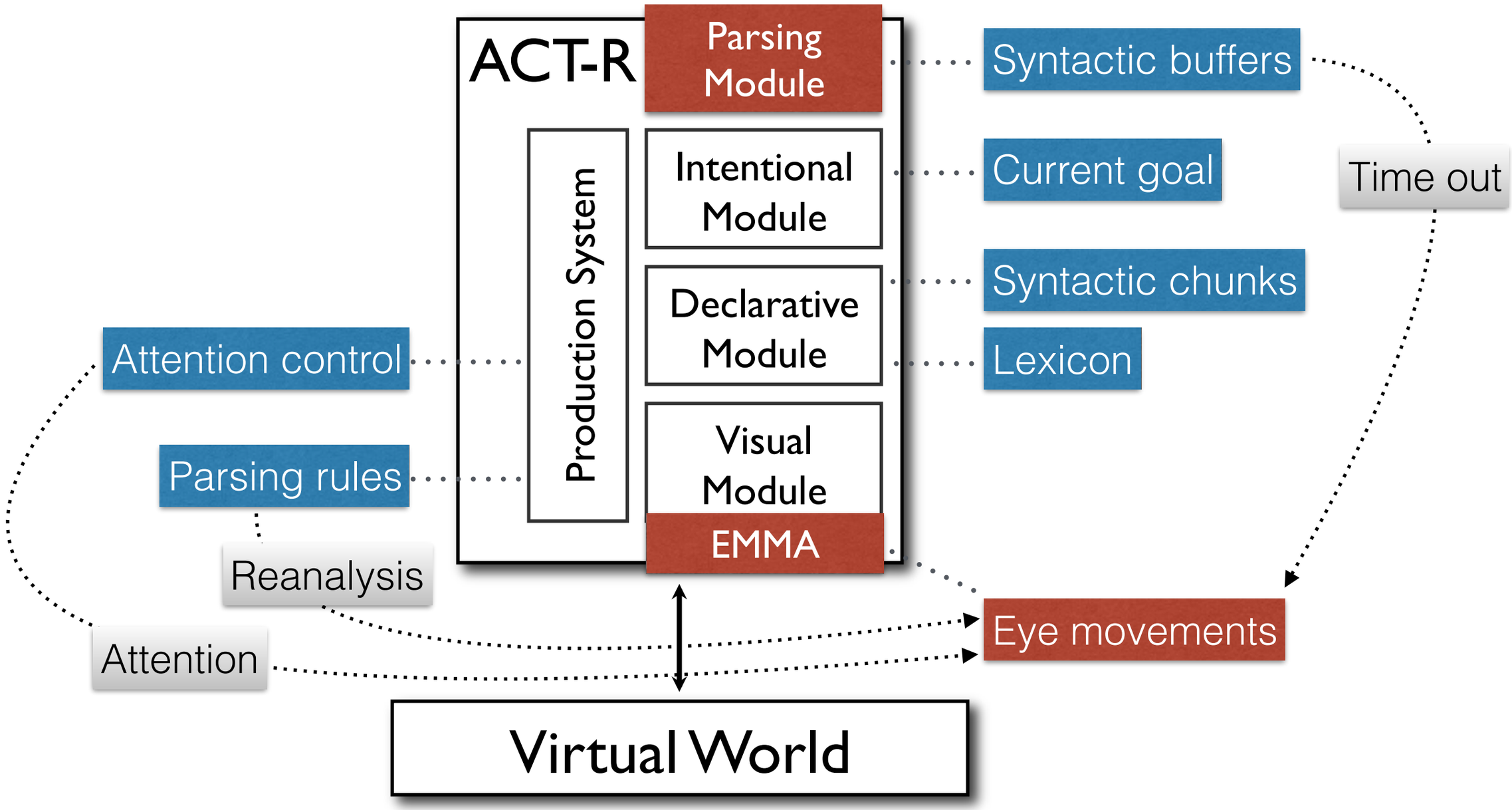


Model Structure



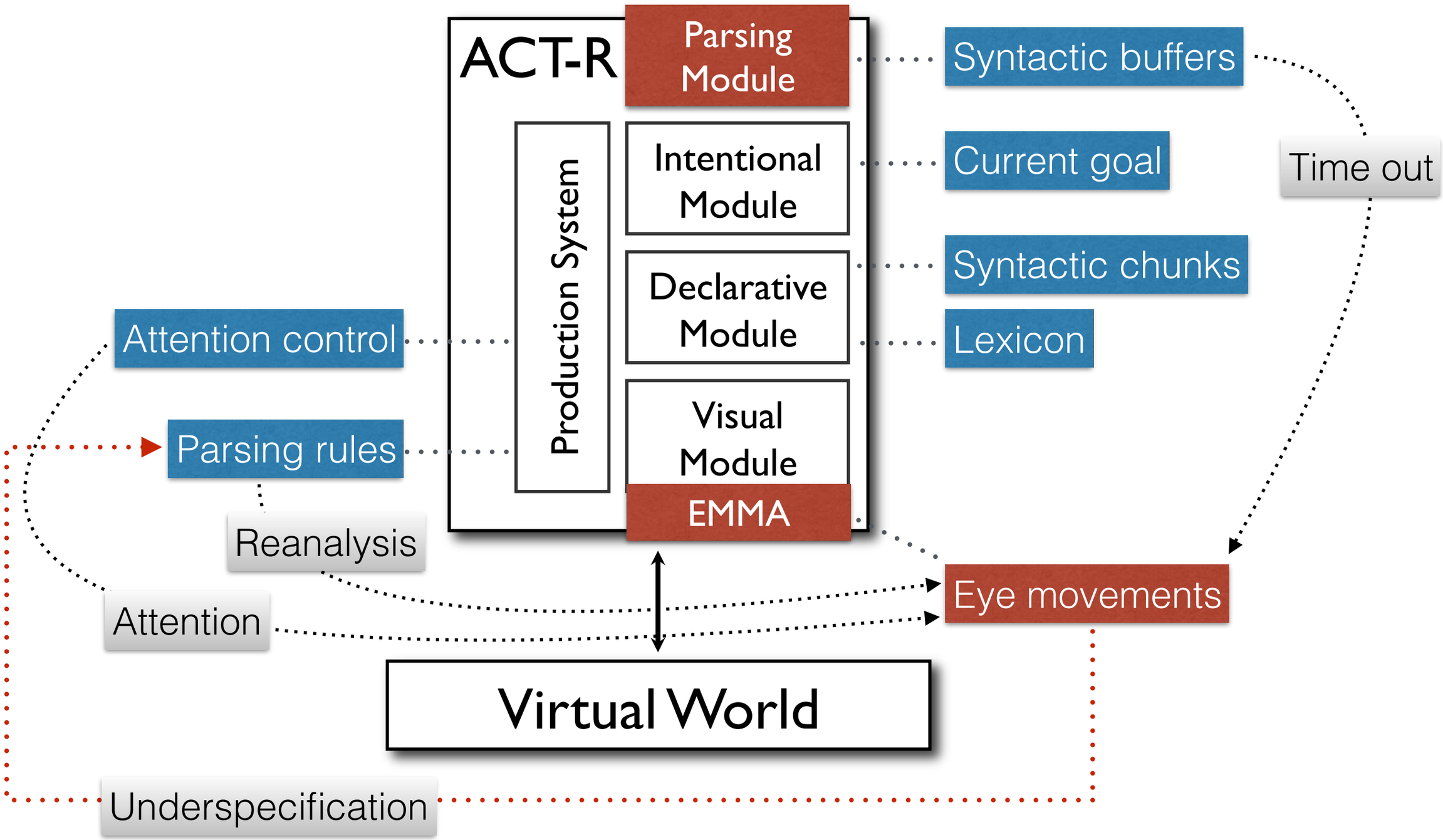
Model Structure

Eye Movement Interaction



Model Structure

Eye Movement Interaction

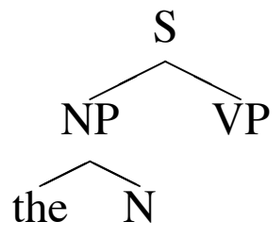


Contents

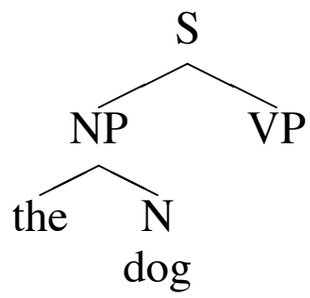
Left-Corner Parsing

$S \rightarrow NP\ VP$ $\quad$ $Det \rightarrow a, the$ $\quad$ $NP \rightarrow Det\ N$
$N \rightarrow man, dog$ $\quad$ $V \rightarrow ran, saw$ $\quad$ $VP \rightarrow V$
$VP \rightarrow V\ NP$

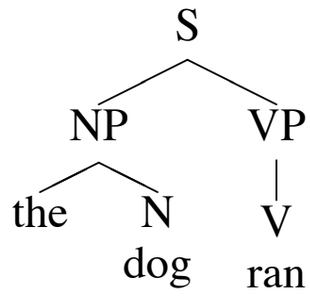
INPUT: *the*
GOAL CATEGORY STACK: [S]
ACTIONS: If *the* is the left corner of any phrase structure rule then replace the stack content with the LHS of that rule. Repeat this left-corner rule until no further steps are possible. Wait for next input word. These actions yield the structure to the right:



INPUT: *dog*
GOAL CATEGORY STACK: [N NP VP S]
ACTIONS: Use the left-corner rule to expand *dog* to N. Since N is predicted in the incremental structure built so far (Step 1), integrate the N built up bottom-up into the tree. Since no further applications of the left-corner rule are possible, wait for the next input.

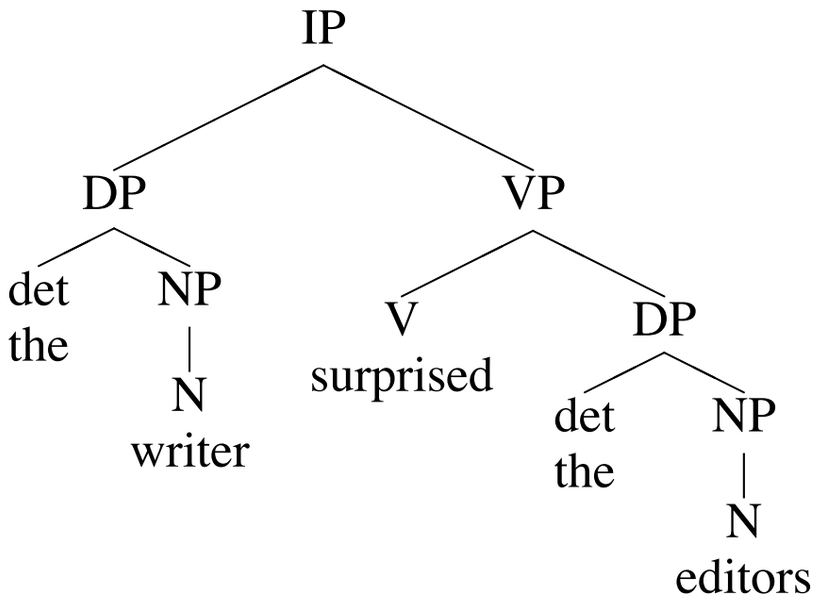


INPUT: *ran*
GOAL CATEGORY STACK: [VP S]
ACTIONS: Use the left-corner rule to expand *ran* to V, and apply this rule once again to expand to VP. Since a VP is predicted in the structure, integrate this with the tree.



Lewis & Vasishth (2005) Parser

The writer surprised the editors.



IP3

cat	:	IP
num	:	sing
spec	:	DP3
comp	:	VP7
tense	:	past
finite	:	finite

DP3

cat	:	DP
num	:	sing
head	:	*the*
comp	:	NP6

NP6

cat	:	NP
case	:	nom
num	:	sing
head	:	*writer*

VP7

cat	:	VP
num	:	sing-plural
tense	:	past
head	:	*surprised*
comp	:	DP9

DP9

cat	:	DP
num	:	plural
head	:	*the*
comp	:	NP14

NP14

cat	:	NP
case	:	acc
num	:	plural
head	:	*editors*

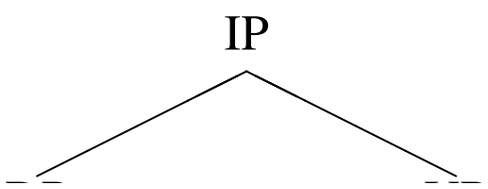
Lewis & Vasishth (2005) Parser

Goal stack

IP

DONE

The writer surprised the editors.



IP3

cat : IP
num :
spec :
comp :
tense :
finite :

Lewis & Vasishth (2005) Parser

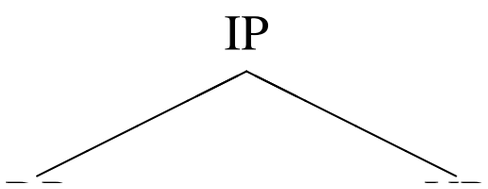
The writer surprised the editors.

Goal stack

IP

DONE

```
(P set-retrieval-cues-IP-goal-input-DET …)
```



IP3

cat : IP
num :
spec :
comp :
tense :
finite :

Lewis & Vasishth (2005) Parser

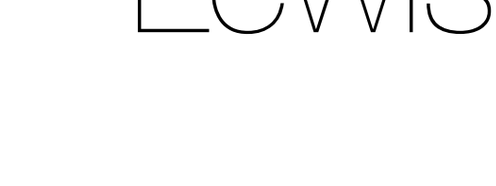
The writer surprised the editors.

Goal stack

IP

DONE

```
(P set-retrieval-cues-IP-goal-input-DET …)
```



Retrieval

IP3

cat : IP
num :
spec :
comp :
tense :
finite :

Lewis & Vasishth (2005) Parser

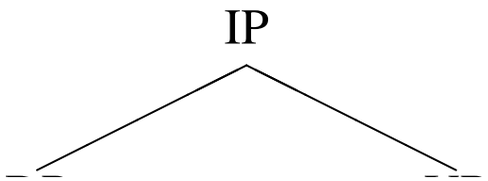
The writer surprised the editors.

Goal stack

IP
DONE

`(P set-retrieval-cues-IP-goal-input-DET …)`

`(P attach-DP-as-subject-of-predicted-IP …)`



Retrieval

IP3

cat	:	IP
num	:	
spec	:	
comp	:	
tense	:	
finite	:	

Lewis & Vasishth (2005) Parser

The writer surprised the editors.

Goal stack

IP
DONE

`(P set-retrieval-cues-IP-goal-input-DET …)`

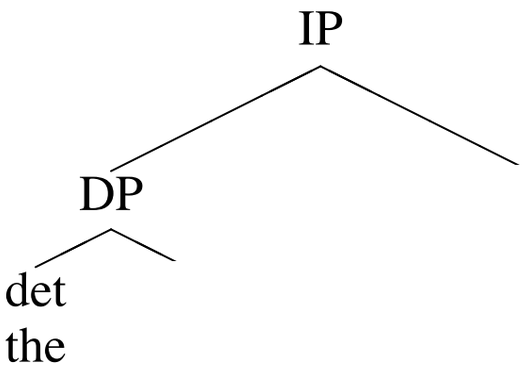
`(P attach-DP-as-subject-of-predicted-IP …)`

Retrieval

Creation

IP3
cat : IP
num :
spec : DP3
comp :
tense :
finite :

DP3
cat : DP
num :
head : *the*
comp :



Lewis & Vasishth (2005) Parser

The writer surprised the editors.

Goal stack

NP
VP
DONE

`(P set-retrieval-cues-IP-goal-input-DET …)`

`(P attach-DP-as-subject-of-predicted-IP …)`

Retrieval

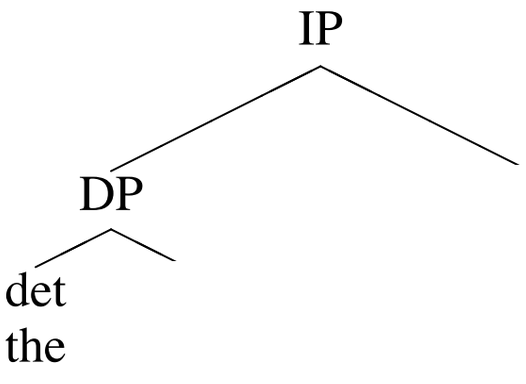
Creation

IP3

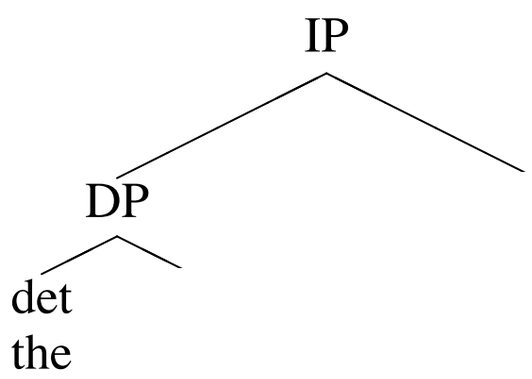
cat	:	IP
num	:	
spec	:	DP3
comp	:	
tense	:	
finite	:	

DP3

cat	:	DP
num	:	
head	:	*the*
comp	:	

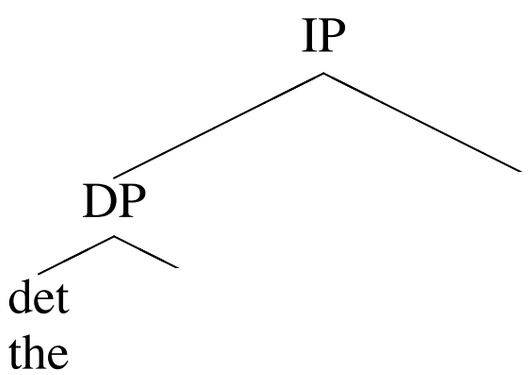


```
(P set-retrieval-cues-IP-goal-input-DET
   =goal>
      ISA                 comprehend-sentence
      state               "read"
      goal-cat            IP-goal
   =retrieval>
      isa                 lexical-entry
      word                =word
      cat                 DET
==>
   =lex> =retrieval
   =goal>
      state               "wm-retrieval"
      cue1                wait-for-IP
   +retrieval>
      ISA                 syn-obj
      waiting-for-cat     wait-for-IP
)
```




```
(P attach-DP-as-subject-of-predicted-IP
   =goal>
      ISA                 comprehend-sentence
      state               "wm-retrieval"
   =retrieval>
      isa                 syn-obj
      cat                 IP
      ID                  =ID-RETR
      head                nil
      waiting-for-cat     wait-for-IP
   =lex>
      isa                 lexical-entry
      cat                 DET
      word                =word
      number              sing-plural-lex
==>
   =goal>
      state               "read"
      goal-cat            NP-goal
   +DPb>
      isa                 syn-obj
      cat                 DP
      ID                  =ID-DP
      head                =word
      spec-of             =ID-RETR
      number              sing-plural
      waiting-for-cat     wait-for-NP
      next-goal           next-VP-goal
   =retrieval>
      spec                =ID-DP
      waiting-for-cat     wait-for-VP
)
```

```
(P set-retrieval-cues-IP-goal-input-DET
   =goal>
      ISA                 comprehend-sentence
      state               "read"
      goal-cat            IP-goal
   =retrieval>
      isa                 lexical-entry
      word                =word
      cat                 DET
==>
   =lex> =retrieval
   =goal>
      state               "wm-retrieval"
      cue1                wait-for-IP
   +retrieval>
      ISA                 syn-obj
      waiting-for-cat     wait-for-IP
)
```

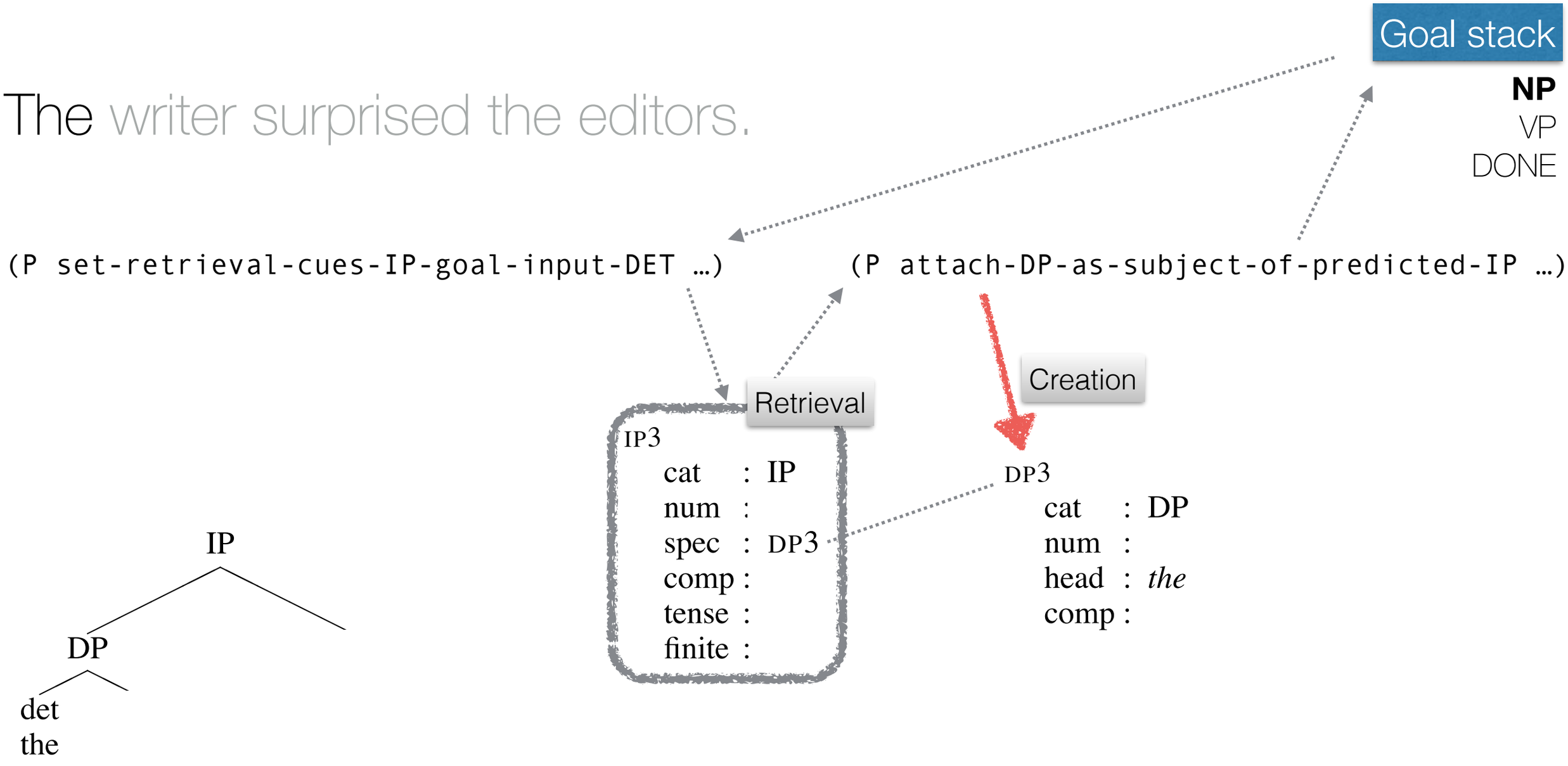



```
(P attach-DP-as-subject-of-predicted-IP
   =goal>
      ISA                 comprehend-sentence
      state               "wm-retrieval"
   =retrieval>
      isa                 syn-obj
      cat                 IP
      ID                  =ID-RETR
      head                nil
      waiting-for-cat     wait-for-IP
   =lex>
      isa                 lexical-entry
      cat                 DET
      word                =word
      number              sing-plural-lex
==>
   =goal>
      state               "read"
      goal-cat            NP-goal
   +DPb>
      isa                 syn-obj
      cat                 DP
      ID                  =ID-DP
      head                =word
      spec-of             =ID-RETR
      number              sing-plural
      waiting-for-cat     wait-for-NP
      next-goal           next-VP-goal
   =retrieval>
      spec                =ID-DP
      waiting-for-cat     wait-for-VP
)
```

Goal stack

Lewis & Vasishth (2005) Parser

The writer surprised the editors.



Lewis & Vasishth (2005) Parser

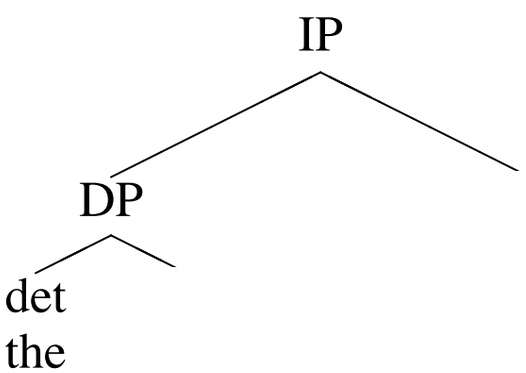
Goal stack

NP
VP
DONE

The writer surprised the editors.

`(P set-retrieval-cues-…)`

`(P attach-…)`



IP3
cat : IP
num :
spec : DP3
comp :
tense :
finite :

DP3
cat : DP
num :
head : *the*
comp :

Lewis & Vasishth (2005) Parser

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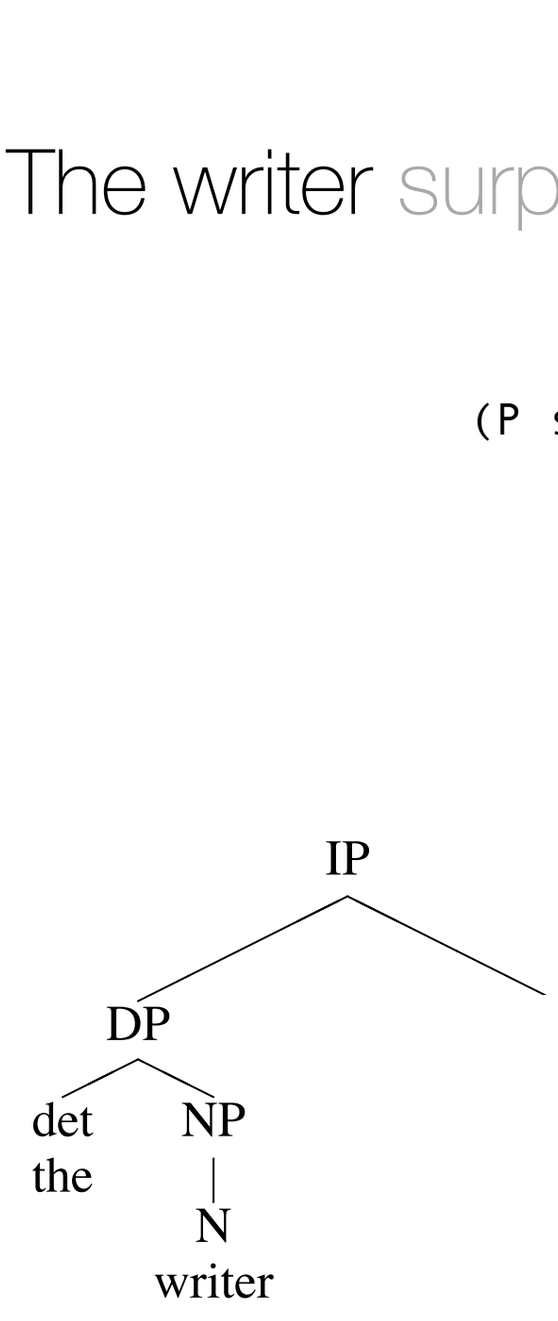
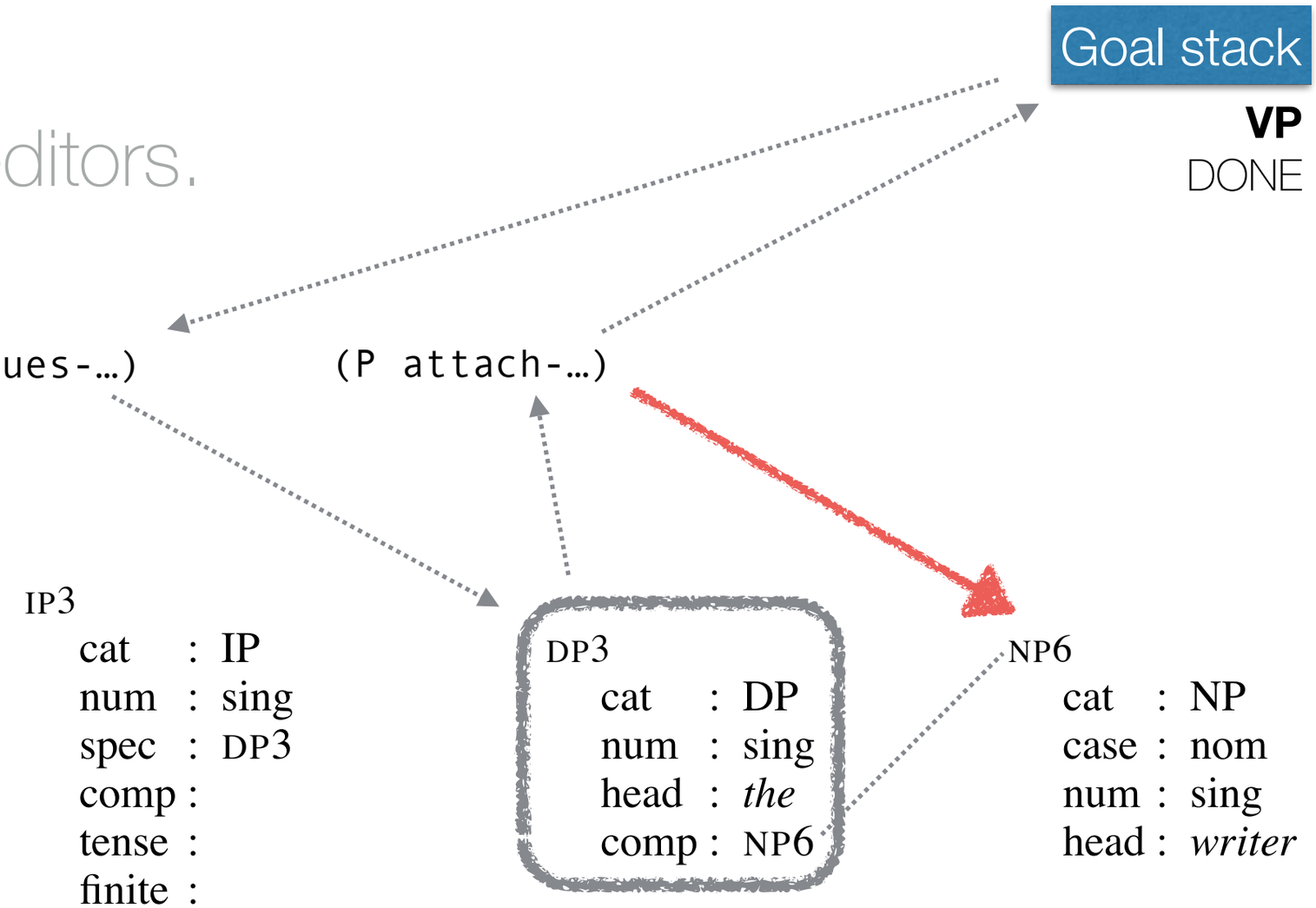




Lewis & Vasishth (2005) Parser

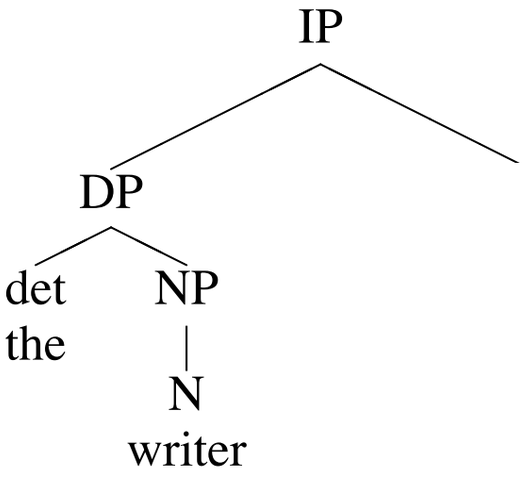
The writer surprised the editors.

Goal stack

VP
DONE

(P set-retrieval-cues-…)

(P attach-…)



IP3

cat	:	IP
num	:	sing
spec	:	DP3
comp	:	
tense	:	
finite	:	

DP3

cat	:	DP
num	:	sing
head	:	*the*
comp	:	NP6

NP6

cat	:	NP
case	:	nom
num	:	sing
head	:	*writer*

Lewis & Vasishth (2005) Parser

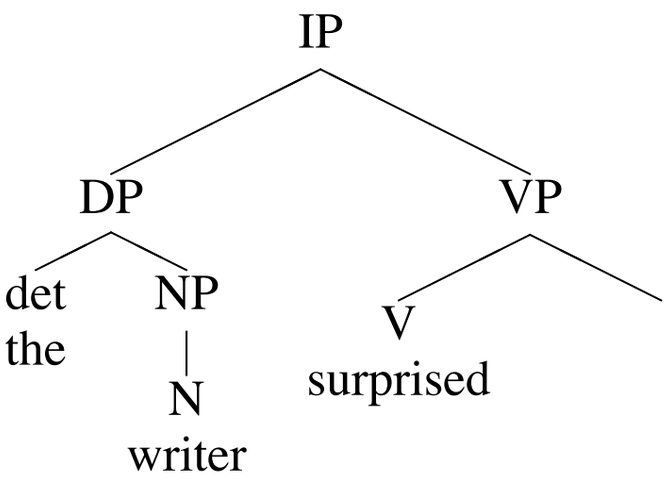
The writer surprised the editors.

Goal stack

DP
DONE

`(P set-retrieval-cues-…)`

`(P attach-…)`



IP3
cat : IP
num : sing
spec : DP3
comp : VP7
tense : past
finite : finite

DP3
cat : DP
num : sing
head : *the*
comp : NP6

NP6
cat : NP
case : nom
num : sing
head : *writer*

VP7
cat : VP
num : sing-plural
tense : past
head : *surprised*
comp :

Lewis & Vasishth (2005) Parser

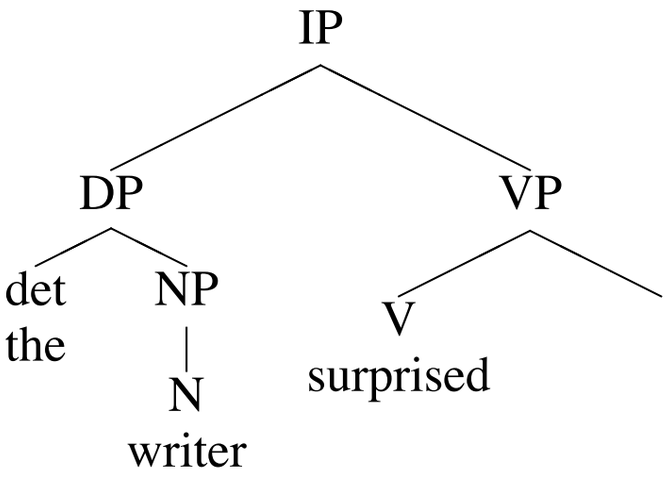
Goal stack

DP
DONE

The writer surprised the editors.

(P set-retrieval-cues-…)

(P attach-…)



IP3

cat	:	IP
num	:	sing
spec	:	DP3
comp	:	VP7
tense	:	past
finite	:	finite

DP3

cat	:	DP
num	:	sing
head	:	*the*
comp	:	NP6

NP6

cat	:	NP
case	:	nom
num	:	sing
head	:	*writer*

VP7

cat	:	VP
num	:	sing-plural
tense	:	past
head	:	*surprised*
comp	:	

Lewis & Vasishth (2005) Parser

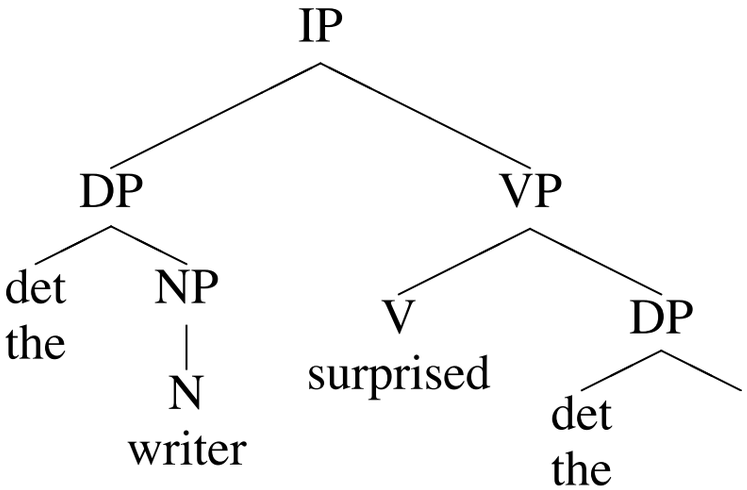
The writer surprised the editors.

Goal stack

NP
DONE

`(P set-retrieval-cues-…)`

`(P attach-…)`



IP3

cat	:	IP
num	:	sing
spec	:	DP3
comp	:	VP7
tense	:	past
finite	:	finite

DP3

cat	:	DP
num	:	sing
head	:	*the*
comp	:	NP6

NP6

cat	:	NP
case	:	nom
num	:	sing
head	:	*writer*

VP7

cat	:	VP
num	:	sing-plural
tense	:	past
head	:	*surprised*
comp	:	DP9

DP9

cat	:	DP
num	:	
head	:	
comp	:	

Lewis & Vasishth (2005) Parser

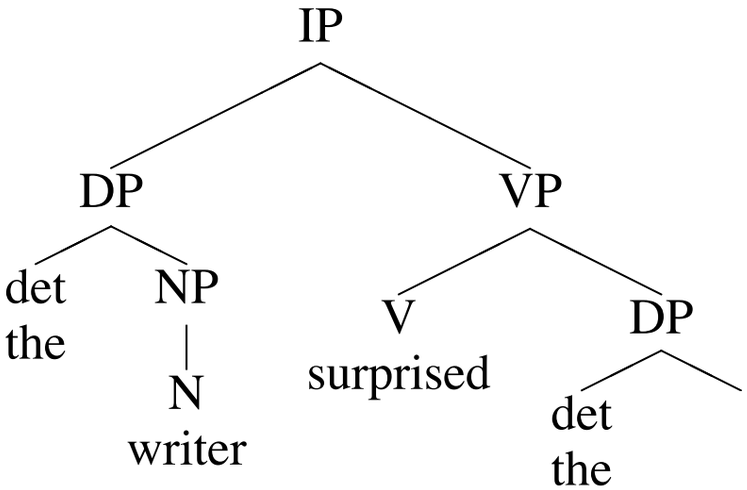
The writer surprised the editors.

Goal stack

NP
DONE

`(P set-retrieval-cues-…)`

`(P attach-…)`



IP3

cat	:	IP
num	:	sing
spec	:	DP3
comp	:	VP7
tense	:	past
finite	:	finite

DP3

cat	:	DP
num	:	sing
head	:	*the*
comp	:	NP6

NP6

cat	:	NP
case	:	nom
num	:	sing
head	:	*writer*

VP7

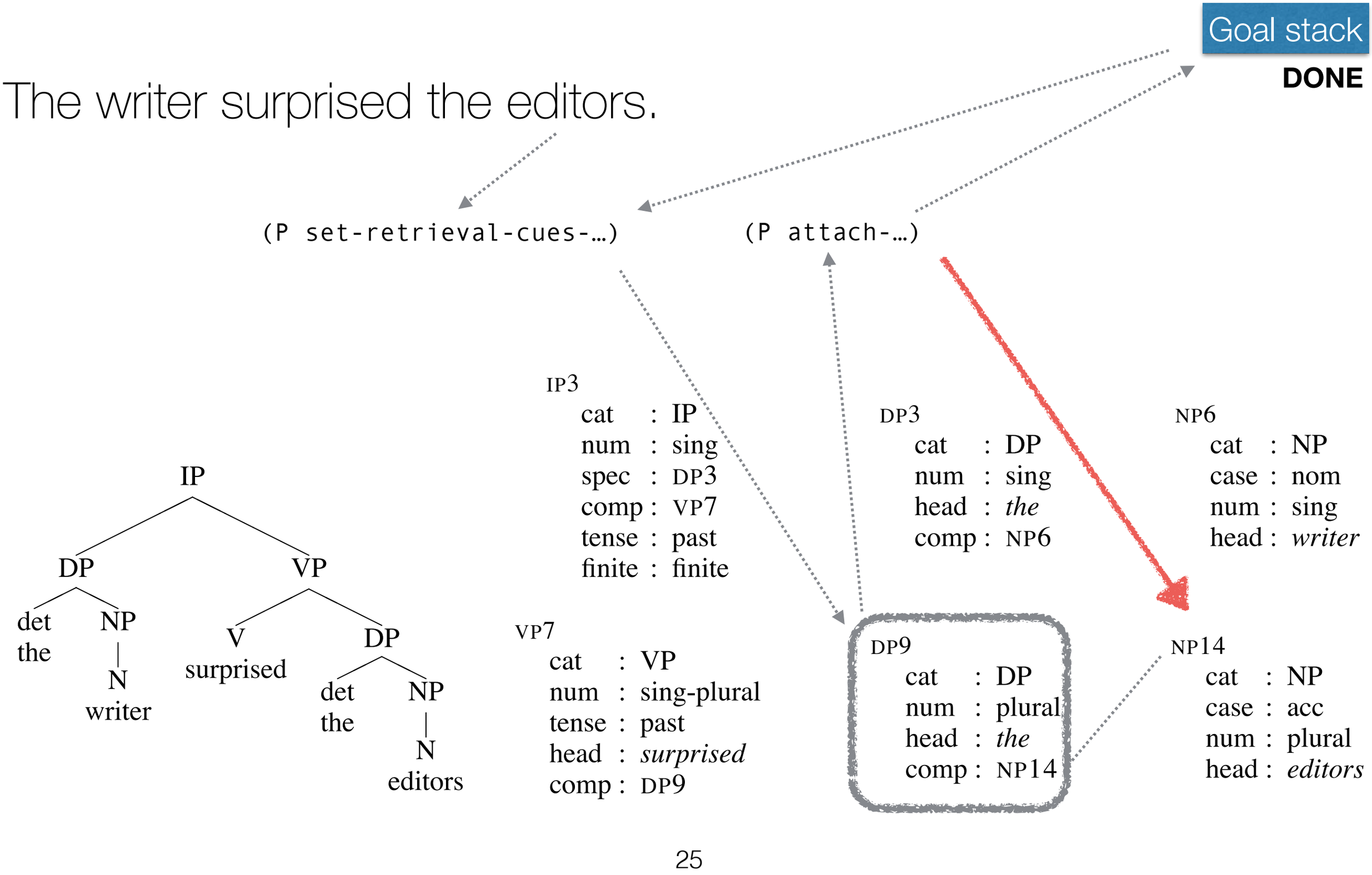
cat	:	VP
num	:	sing-plural
tense	:	past
head	:	*surprised*
comp	:	DP9

DP9

cat	:	DP
num	:	
head	:	
comp	:	

Lewis & Vasishth (2005) Parser

The writer surprised the editors.



Lewis & Vasishth (2005) Parser

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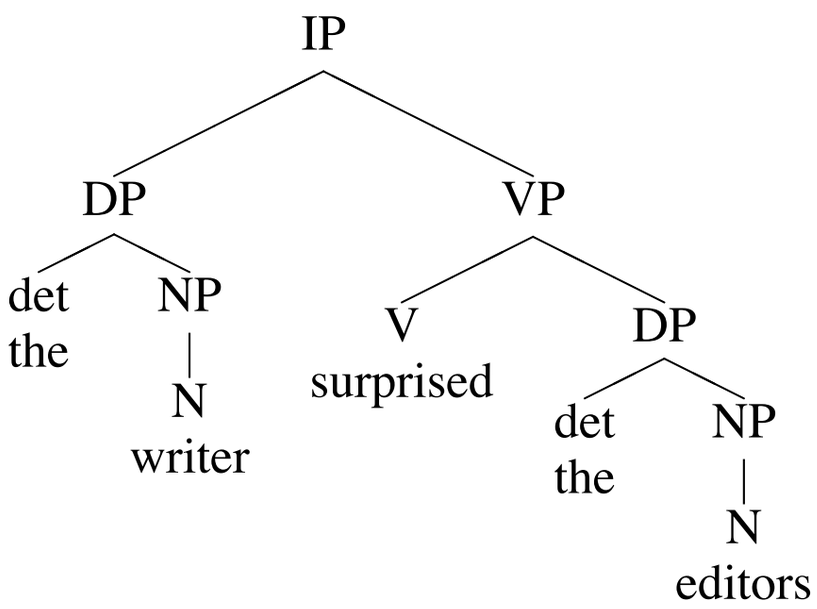
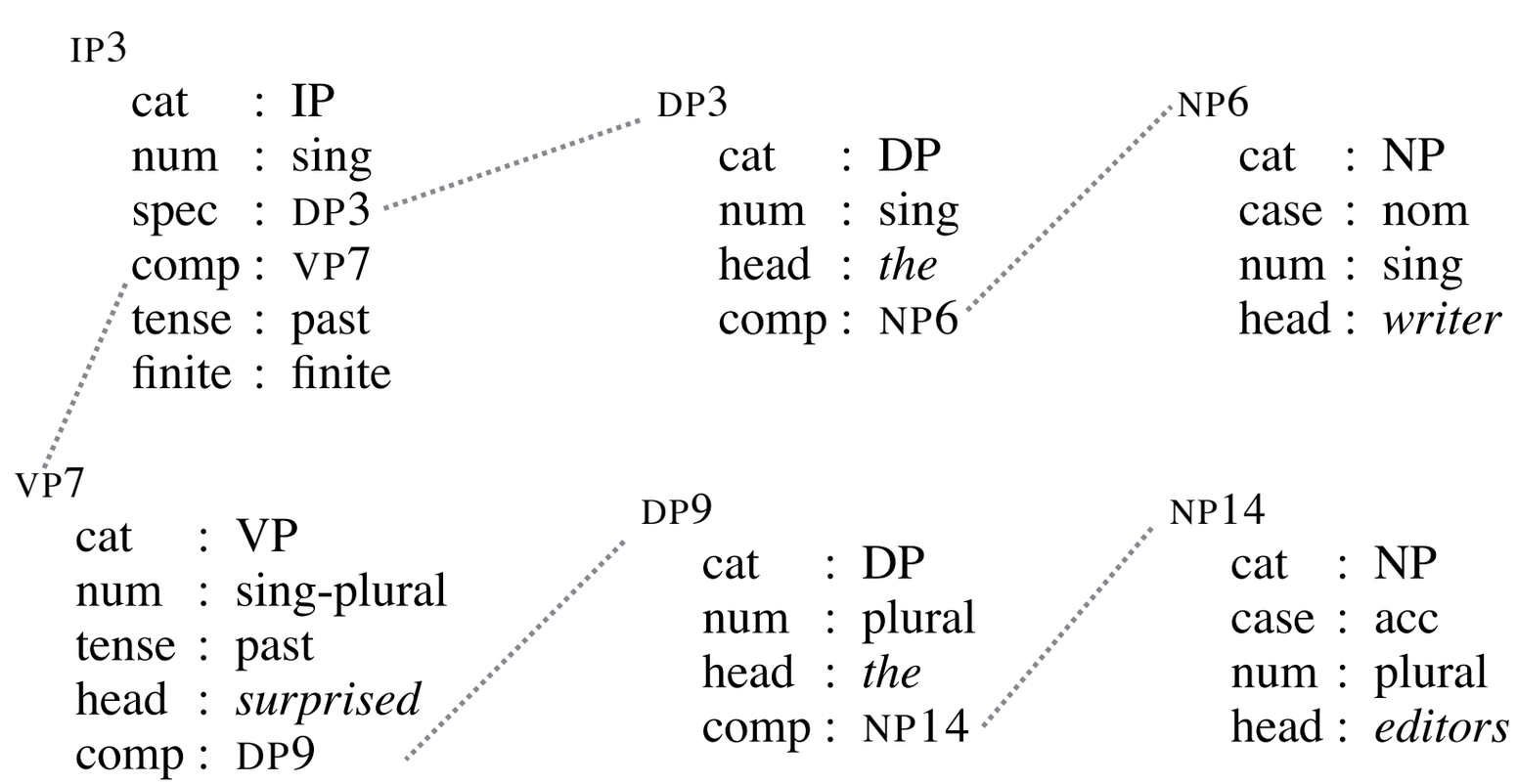
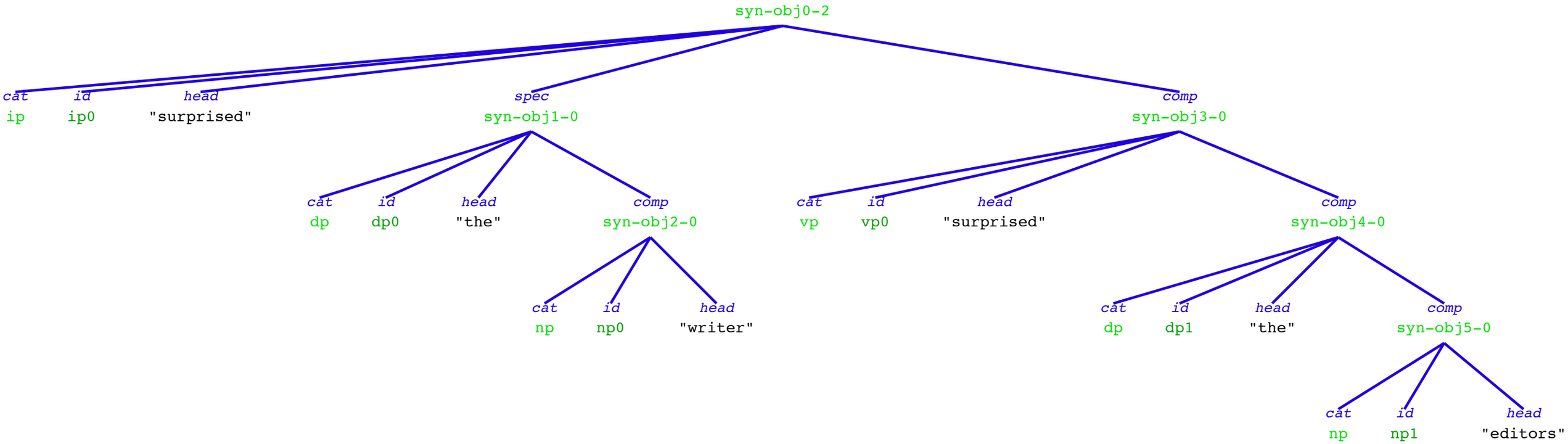




Lewis & Vasishth (2005) Parser

The writer surprised the editors.



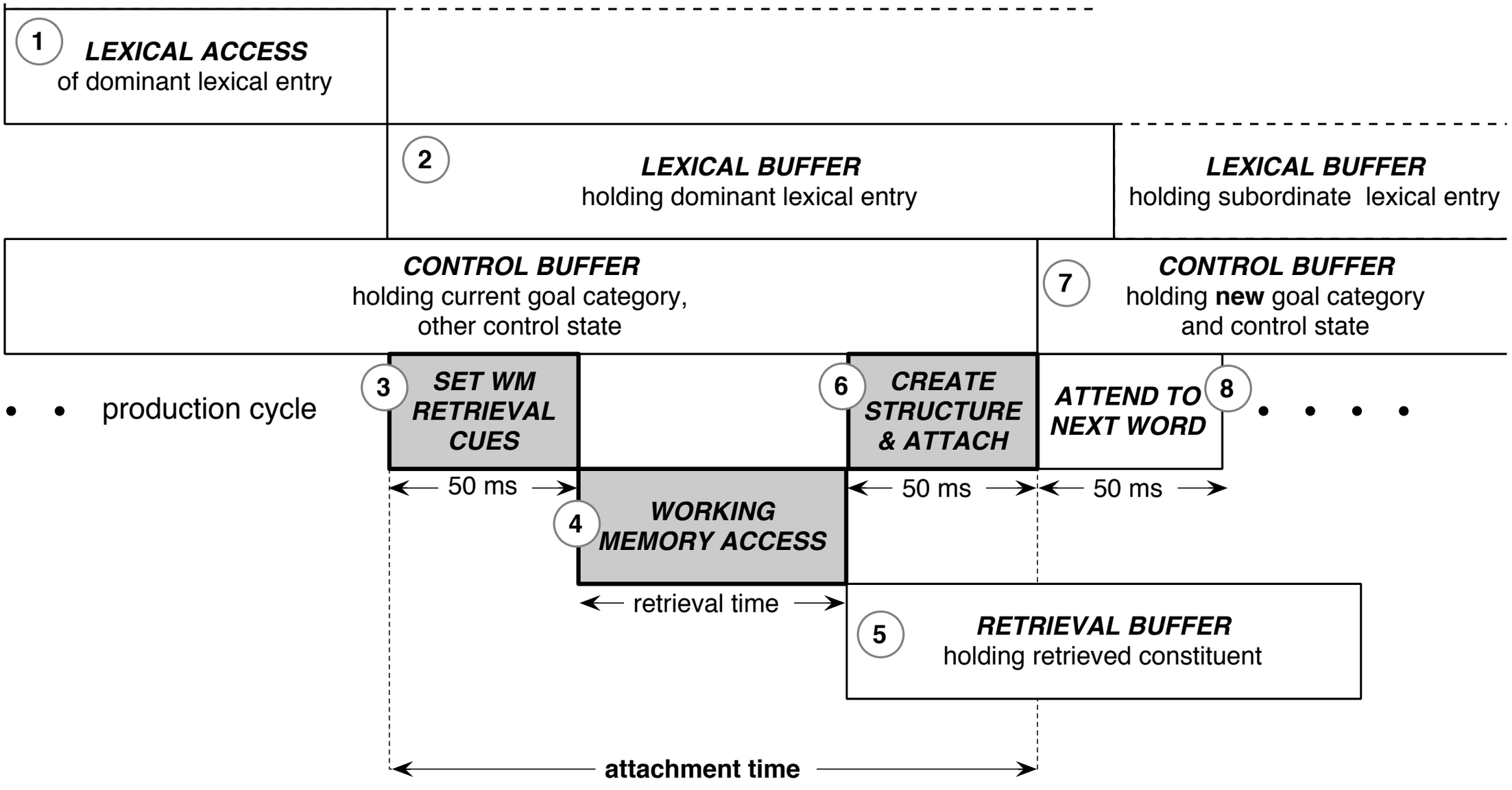

```
(ps "the writer surprised the editors *")
```

or just:

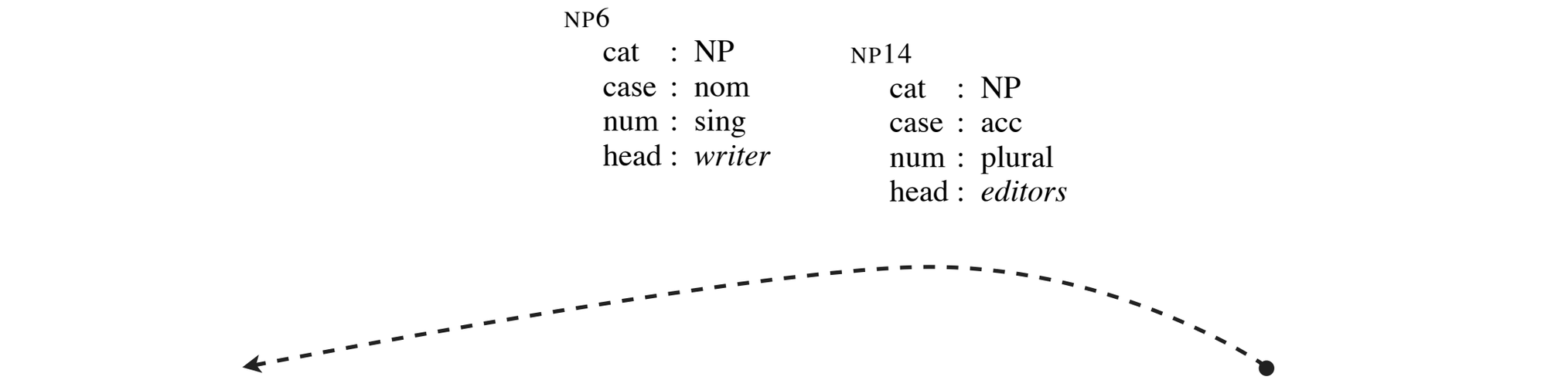
```
(demo)
```

for „the dog bit the boy“

Lewis & Vasishth (2005) Parser



Lewis & Vasishth (2005) Parser



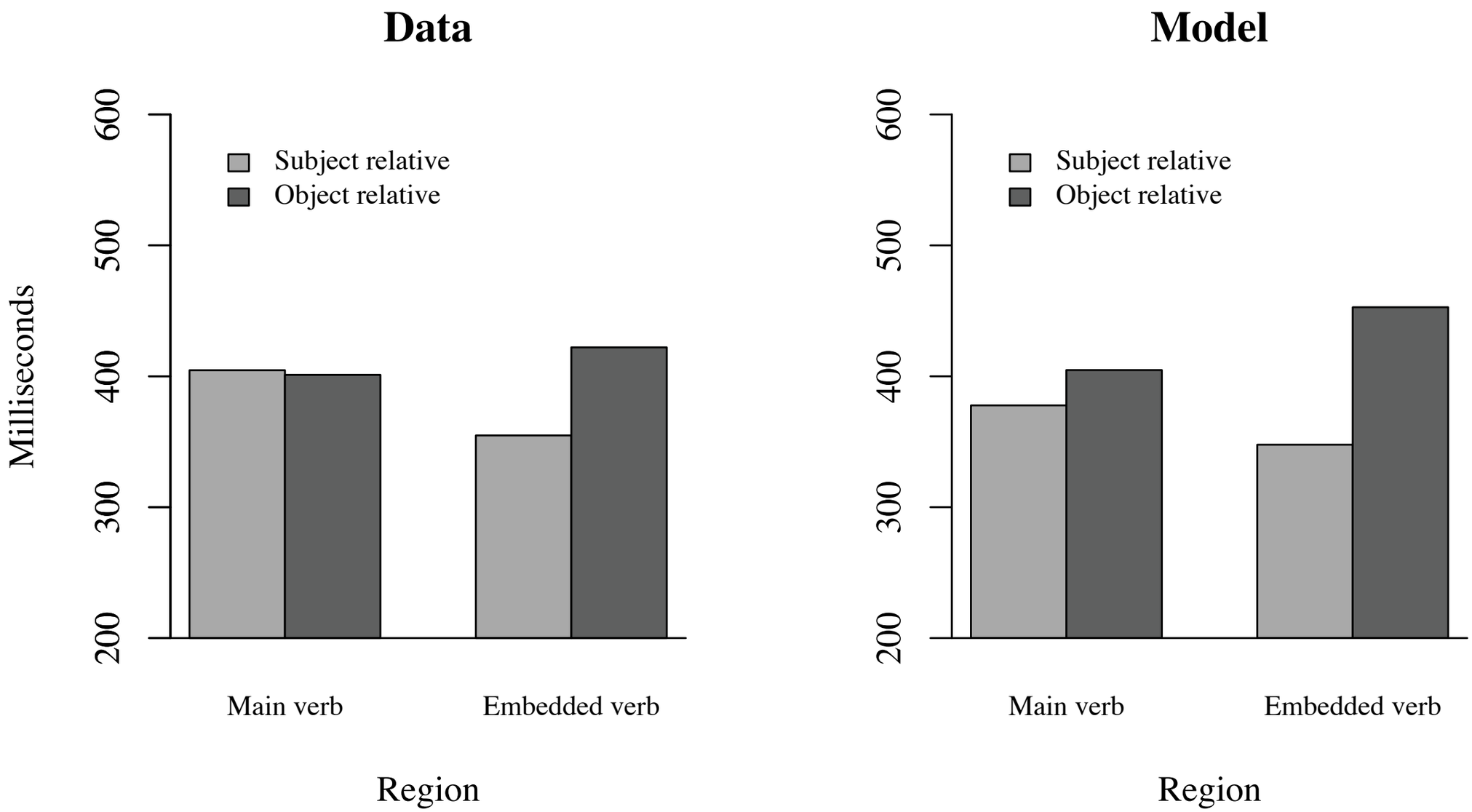
- Activation decay —> distance effects
- Associative retrieval —> Similarity-based interference
- Deterministic rule application —> Expectation effects, reanalysis

Example: Relative Clauses

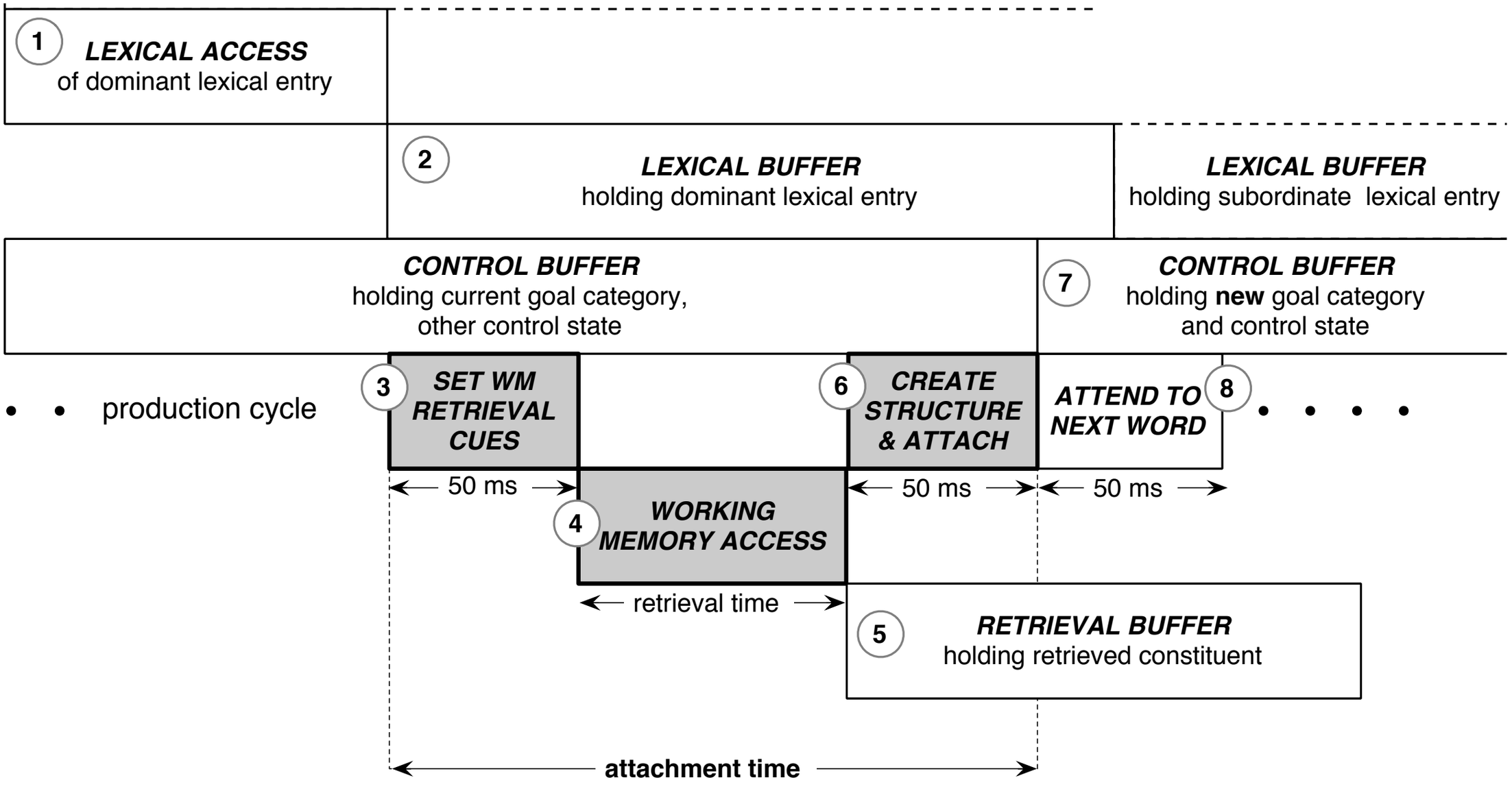
Grodner & Gibson (2005)

SR: The reporter who sent the photographer to the editor hoped for a story.

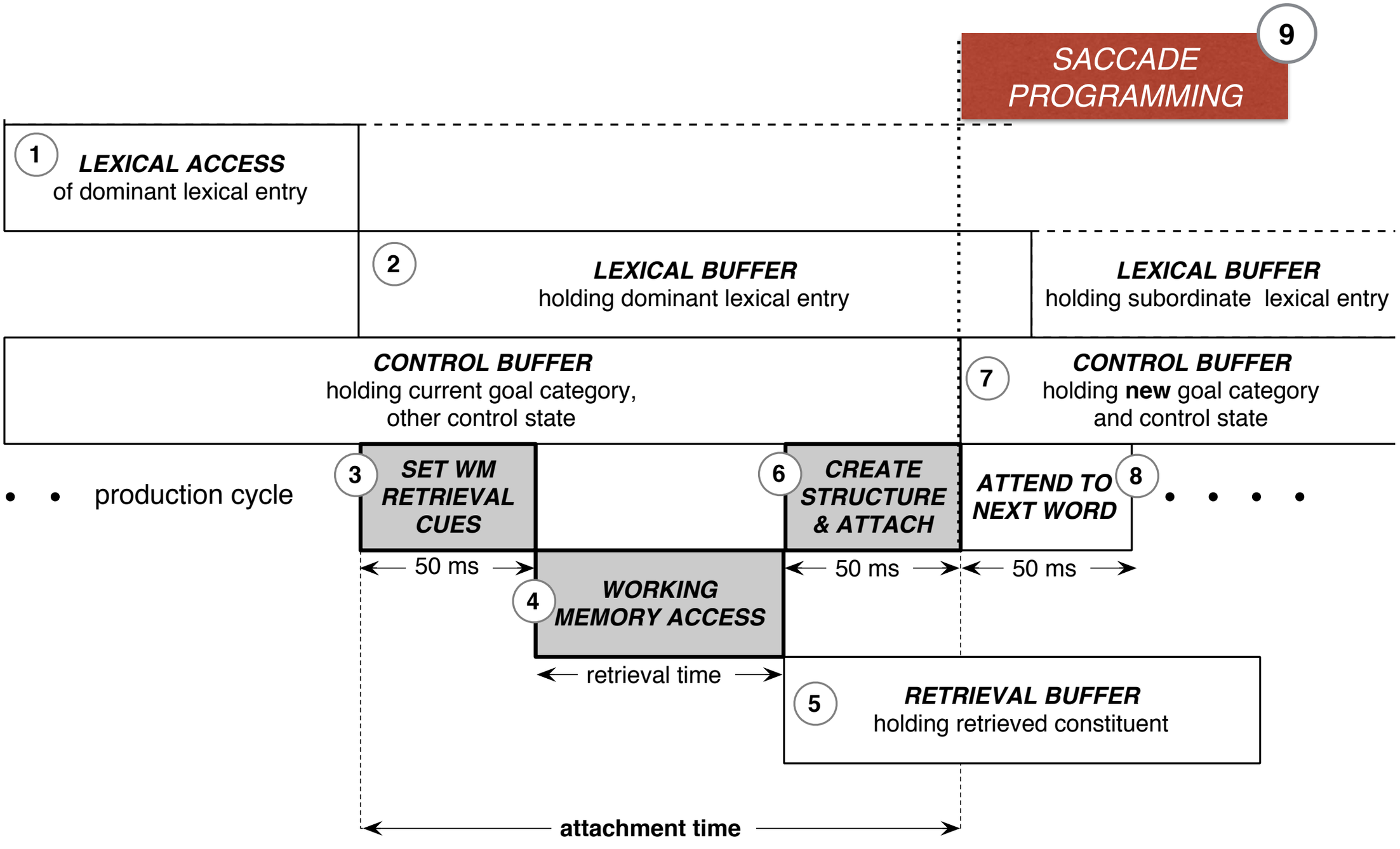
OR: The reporter who the photographer sent to the editor hoped for a story.



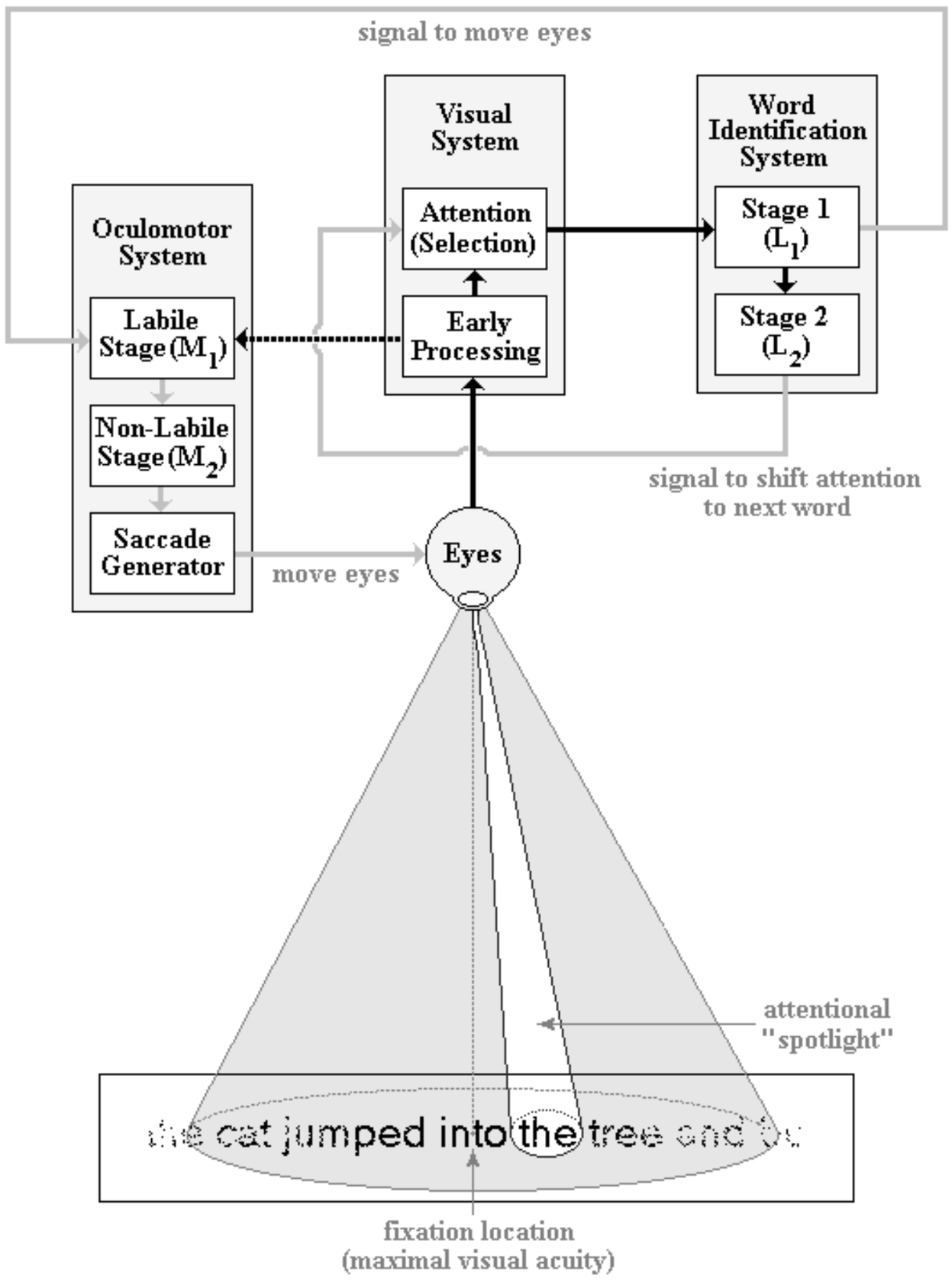
Eye Movements



Eye Movements



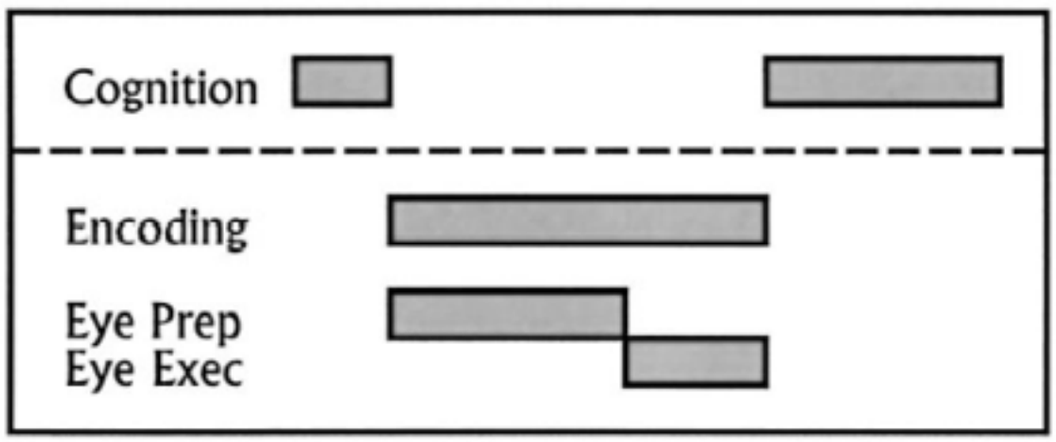
E-Z Reader 7 (Reichle et al., 2003)



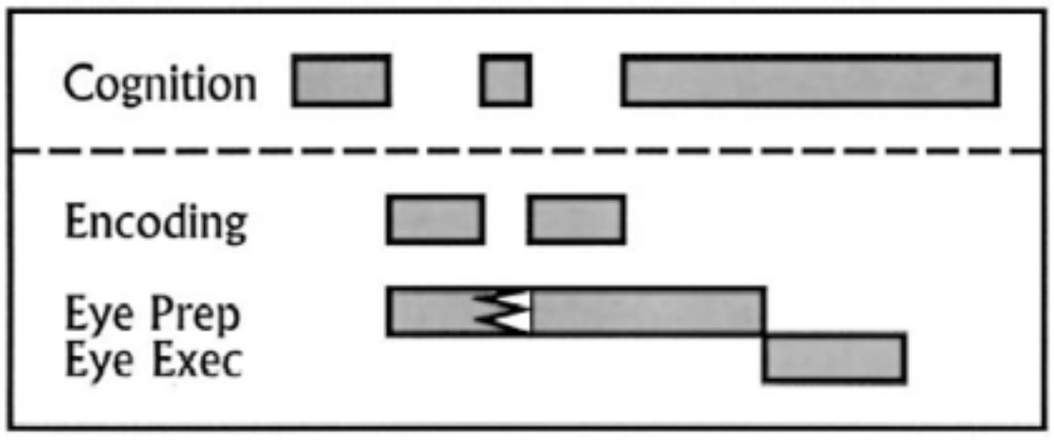
EMMA (Salvucci, 2001)

A simplified version of E-Z Reader for cognitive control models

Normal progression:



Skipping:



Encoding time:

$$T_i = K(-\log f_i)e^{k\varepsilon_i}$$

- Encoding factor
- Word frequency
- Encoding exponent
- Word eccentricity

Saccades:

- 135 ms preparation (Salvucci default)
- 50 ms motor programming
- Execution: 20 ms execution + 2 ms per degree of visual angle

Parameters:

```
:VISUAL-ENCODING-FACTOR     0.002
:VISUAL-ENCODING-EXPONENT   0.4
:SACCADE-PREPARATION-TIME   0.110
```

How to interact with parsing?

- We know that parsing lags behind eye movements (late effects and spill-over) but, still, integration difficulty influences fixation targets and durations.

Selective Reanalysis (Frazier & Rayner, 1982): Regressions are tightly coupled with linguistic operations.

Time Out proposal (Mitchell et al., 2008): „Regressions are programmed not to facilitate repair, but merely to buy time for the linguistic processor to catch up with its existing backlog of processing.“

Reichle et al. (2009): „The average length of readers' initial regressive eye movements are often quite short, moving the eyes back only a word or two.“

Mitchell et al. (2008): „Regression sequences triggered by syntactic disambiguation are placed under relatively loosely-coupled control with the guidance of successive fixations being shared between both linguistic and non-linguistic mechanisms.“

How to interact with parsing?

Implementation of a Time Out mechanism in Reichle et al. (2009)'s E-Z Reader 10 in terms of a linear-order requirement:

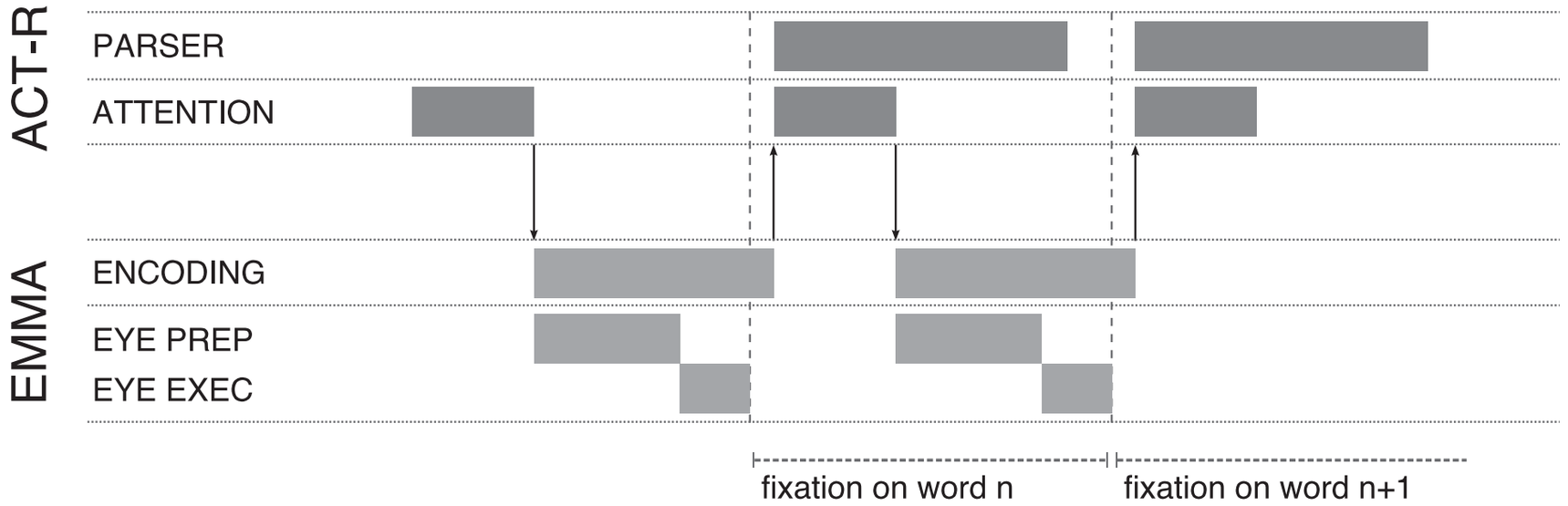
> „… word n+1 is identified … before word n has been integrated, which … halts both the post-lexical processing … of word n and the forward movement of the eyes … so that both attention and the eyes can be directed back …"

- But what about fixation durations?

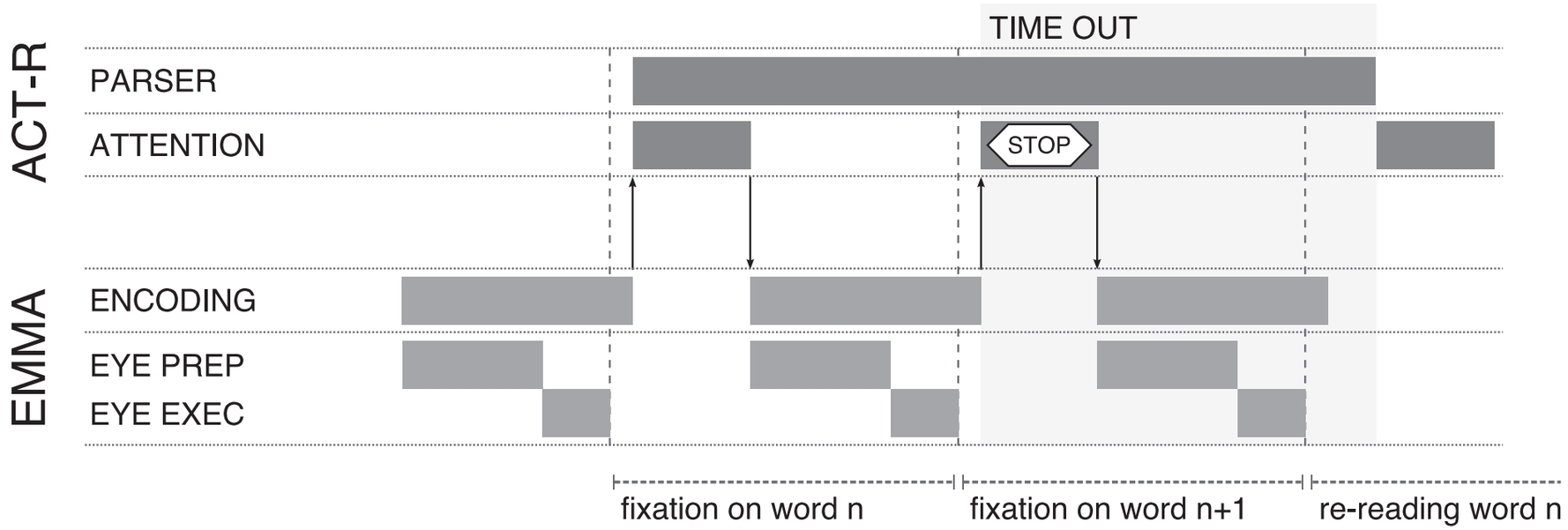
Slowed reading as a by-product of Time Out: When the delayed integration finishes before the regression is executed, the extra processing time of the then cancelled saccade leads to an inflated reading time.

Time Out (Mitchell et al., 2008)

SR: The reporter who **sent** the photographer to the editor hoped for a story.



OR: The reporter who the photographer **sent** to the editor hoped for a story.



```
(p start-time-out
    =goal>
       ISA             comprehend-sentence
       state           "wm-retrieval"
       em-state        "attending"
       attend-to       "next-word"
       time-out        nil
    ?visual>
       processor       free                ;; no current encoding
       execution       free                ;; no current saccade execution
    =visual>
       ISA             text
       screen-pos      =visual-location
==>
    !bind! =eye-loc (first (current-eye-loc))
    !bind! =parse-loc (parsing-get-loc)
    =goal>
       em-state        "looking"
       last-loc        =visual-location
       time-out        t
   +visual-location>
        ISA            visual-location
      < screen-x       =eye-loc          ;; target before current fixation
        screen-x       highest           ;; target nearest to the left

   !eval! (start-time-out =parse-loc)
   !eval! (trialmessage "timeout" =eye-loc)
)
```

Corpus Evaluation

```
:lf 0.2
:VISUAL-ENCODING-FACTOR    0.002
:VISUAL-ENCODING-EXPONENT  0.4
:SACCADE-PREPARATION-TIME  0.110
```

TOPICS IN COGNITIVE SCIENCE

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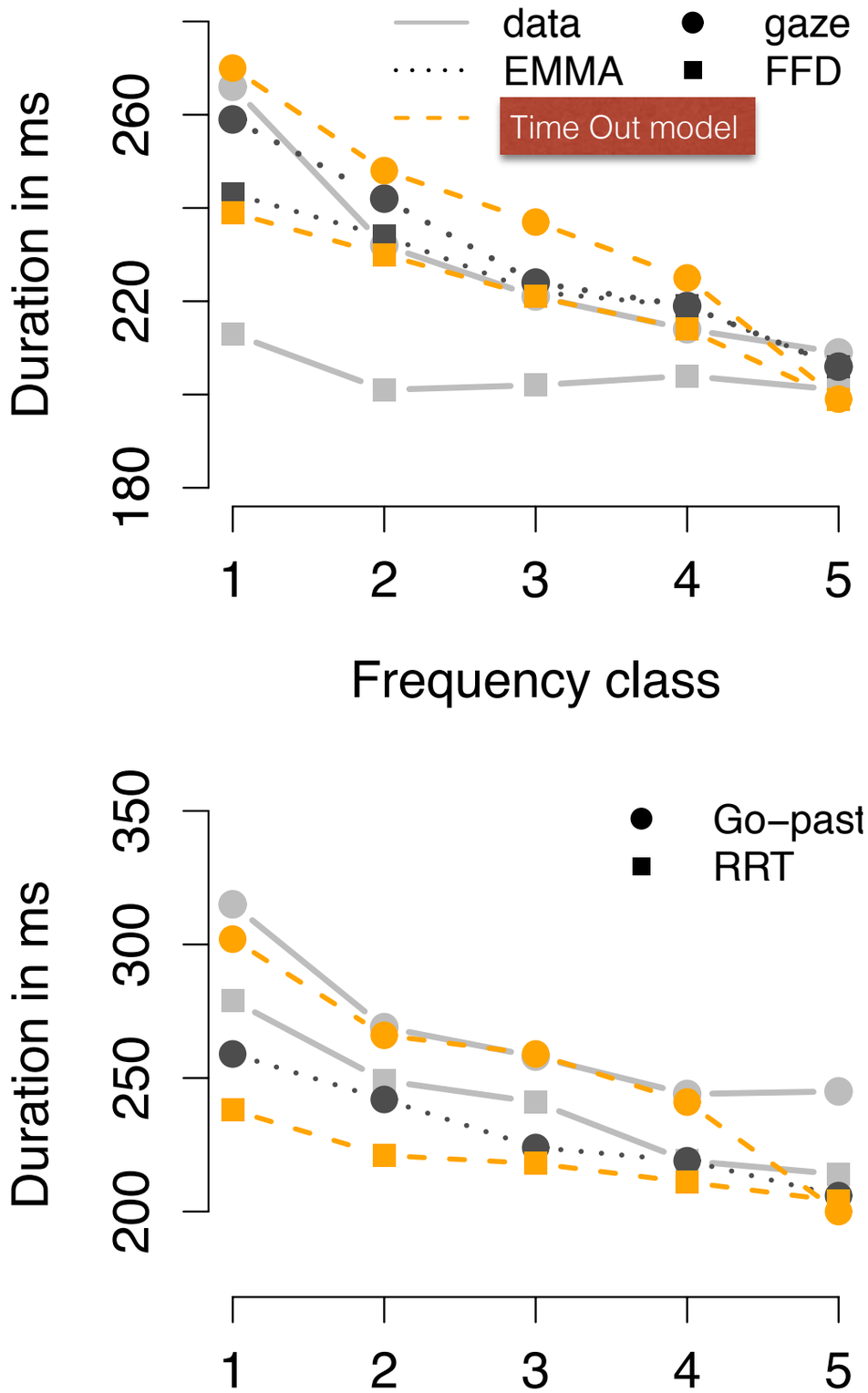
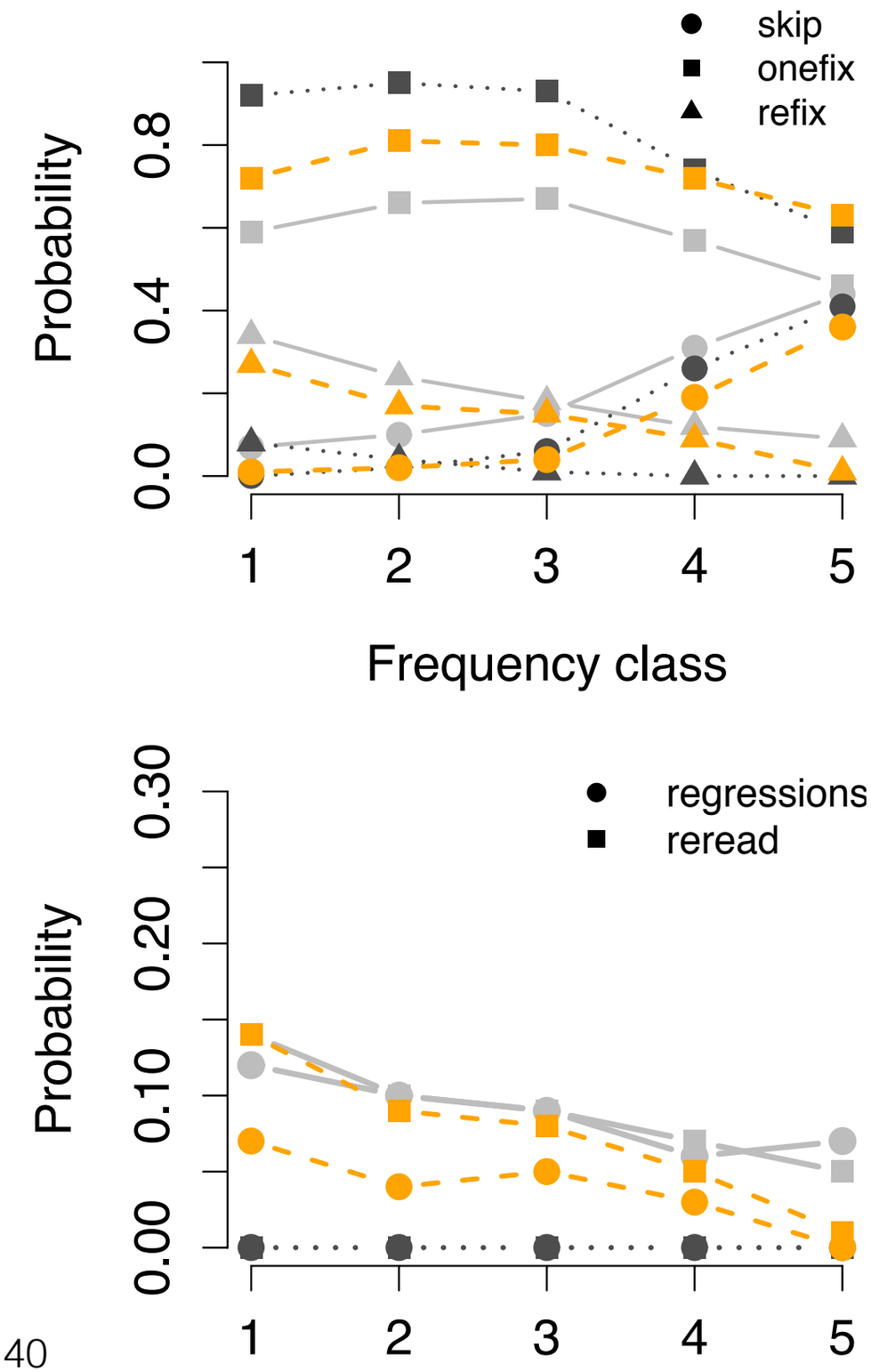
DOI: 10.1111/tops.12026

A Framework for Modeling the Interaction of Syntactic Processing and Eye Movement Control

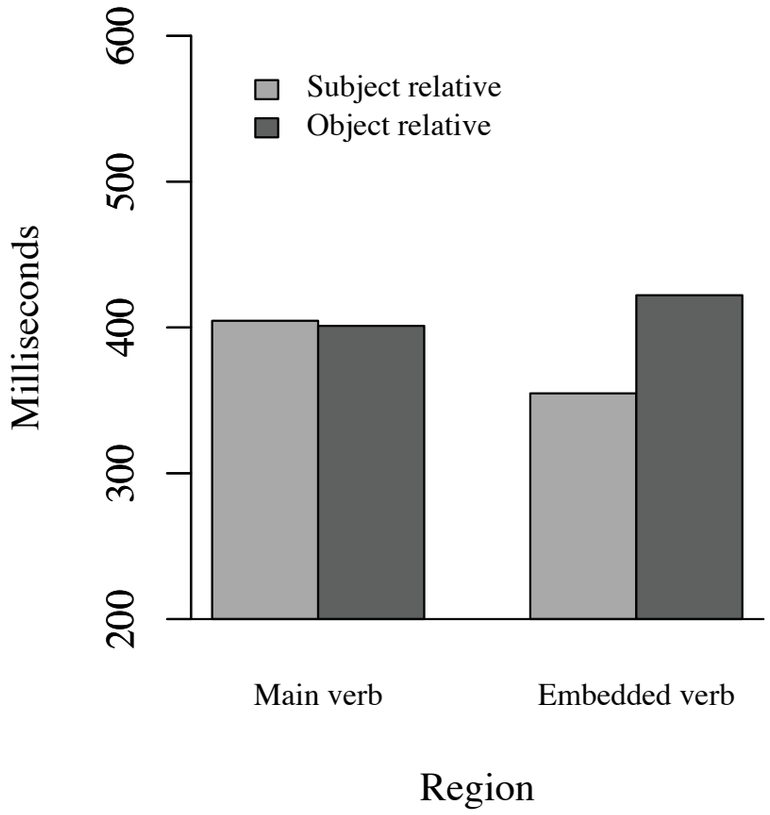
Felix Engelmann, Shravan Vasishth, Ralf Engbert, Reinhold Kliegl

Corpus Evaluation

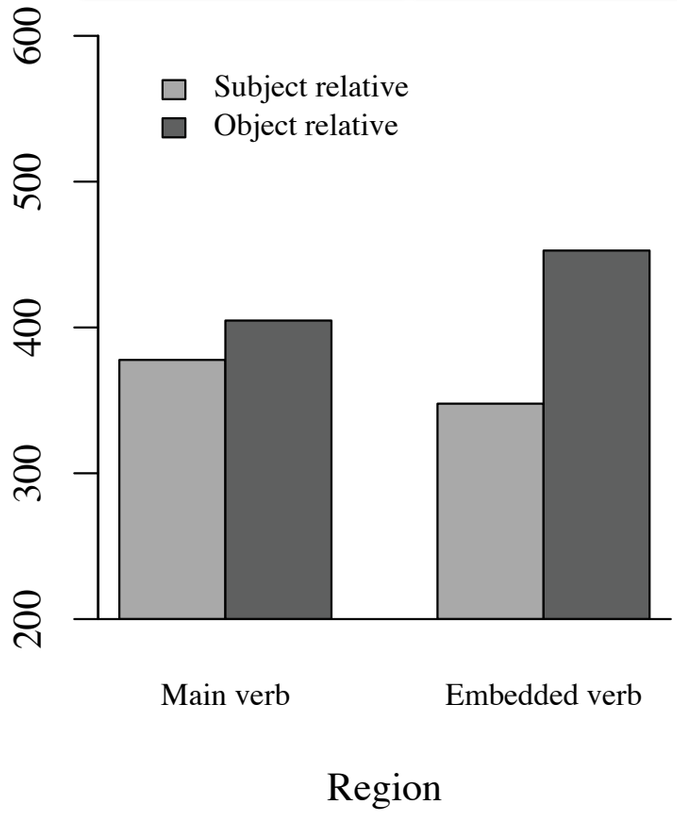




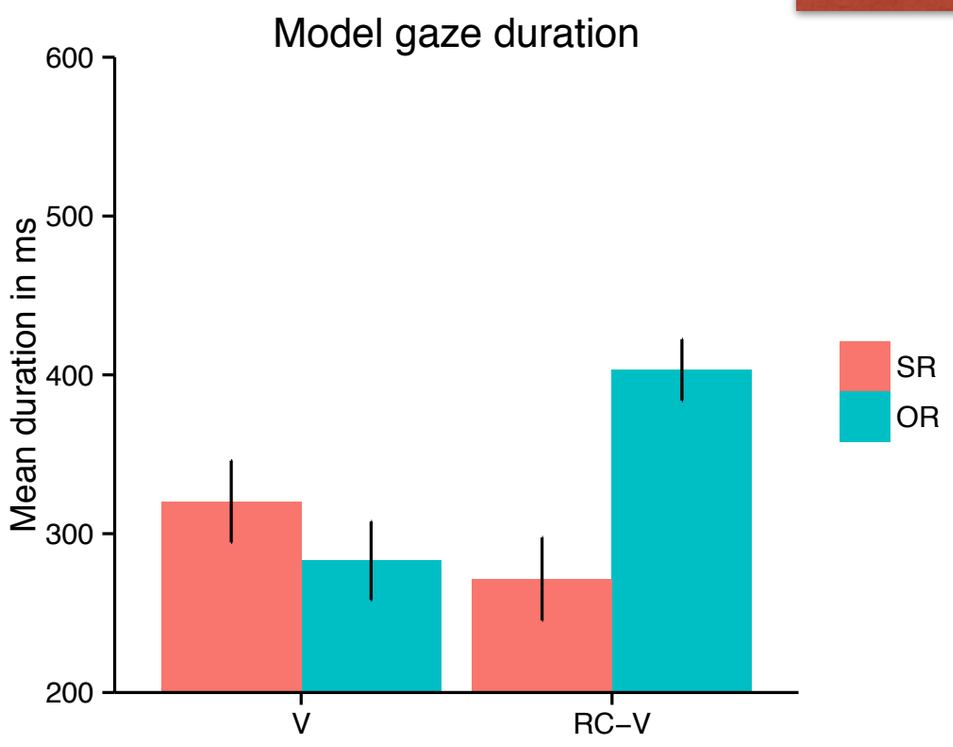
Grodner & Gibson (2005)

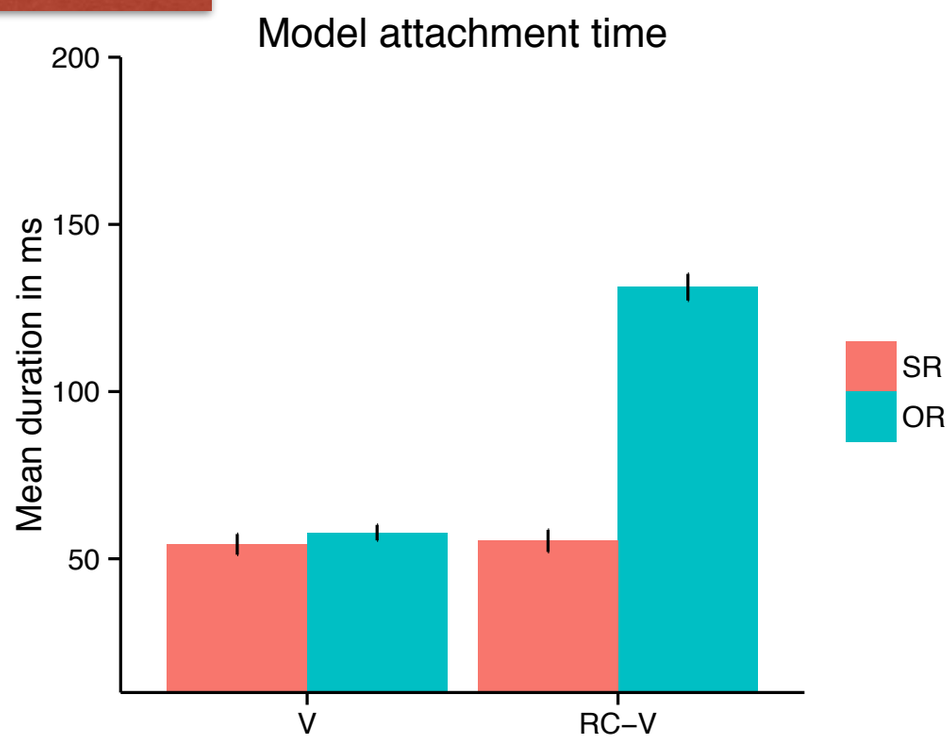


Attachment LV05 model



Time Out model

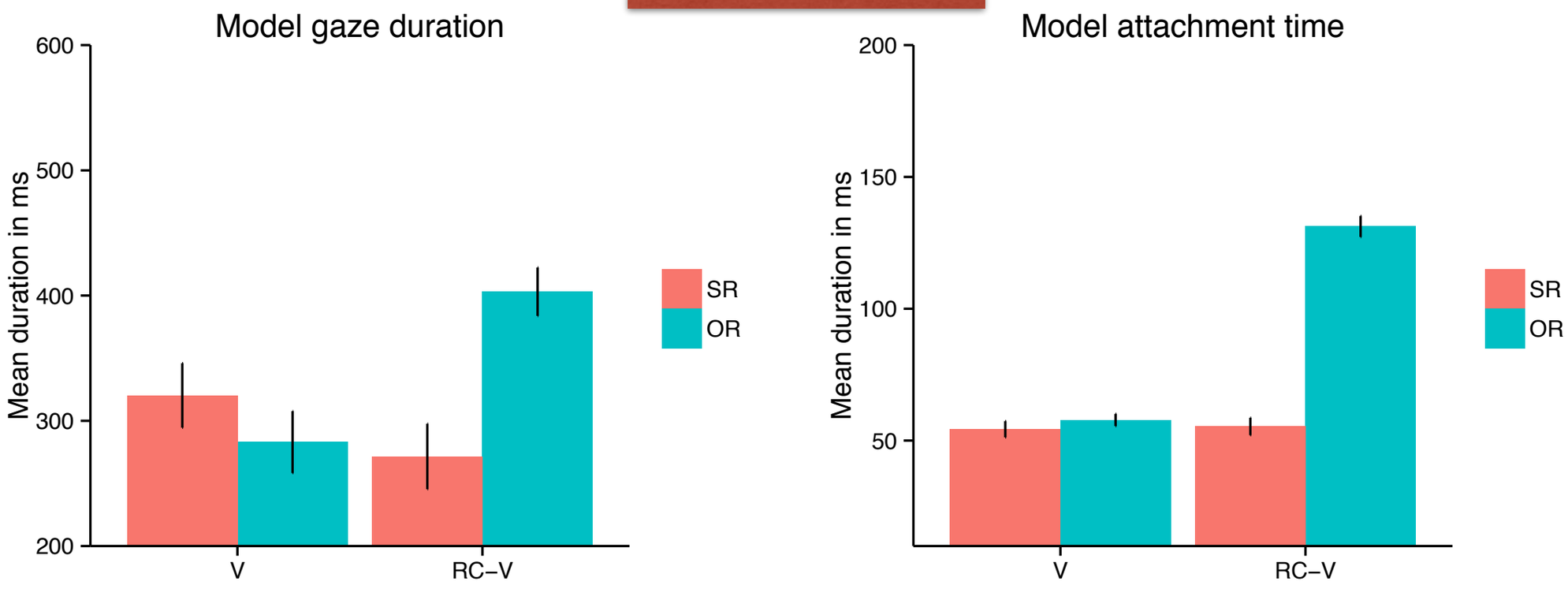




Grodner & Gibson (2005)

```
(re 'gg-exp1 100)
(cwd "output/")
(run-program "Rscript" '("gg05-analysis.R"))
(cwd "../")
```

Time Out model

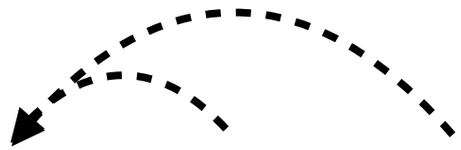


Reanalysis: Staub (2010)

Subject-relative:

The employees that noticed the fireman hurried across the open field.

Object-relative:



The employees that the fireman noticed hurried across the open field.

Reanalysis: Staub (2010)

Subject-relative:

The employees that noticed the fireman hurried across the open field.

Object-relative:

Reanalysis regression (fast)

Expectation

The employees that the fireman noticed hurried across the open field.

Memory

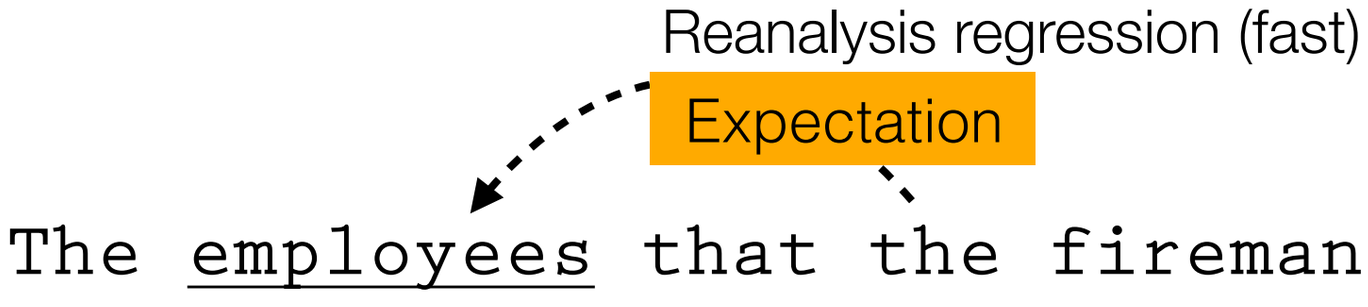
Time Out (slow — and mostly cancelled)

„The difficulty that emerges on the ORC subject and verb are apparently different in kind.“

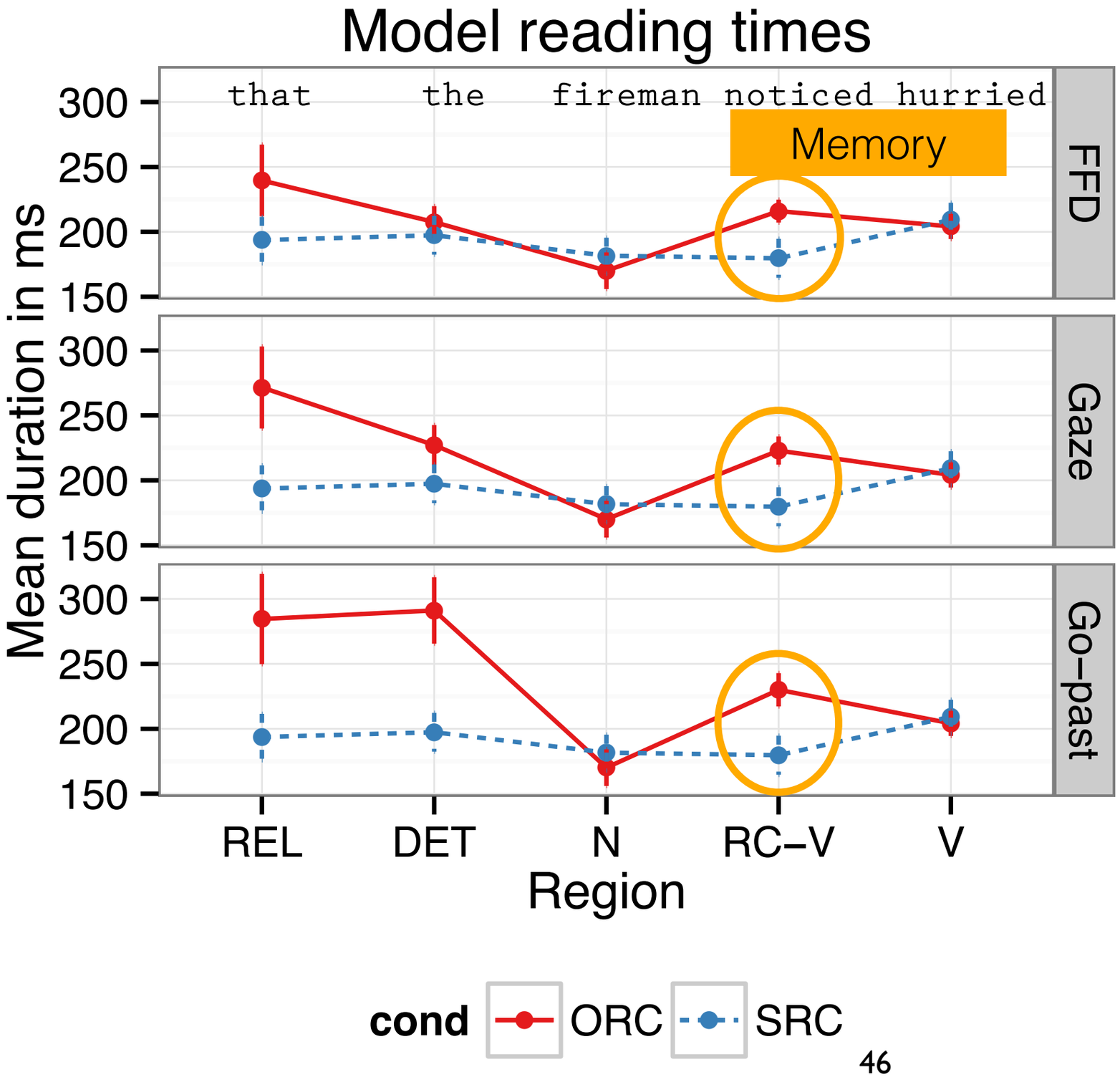
(Staub, 2010)

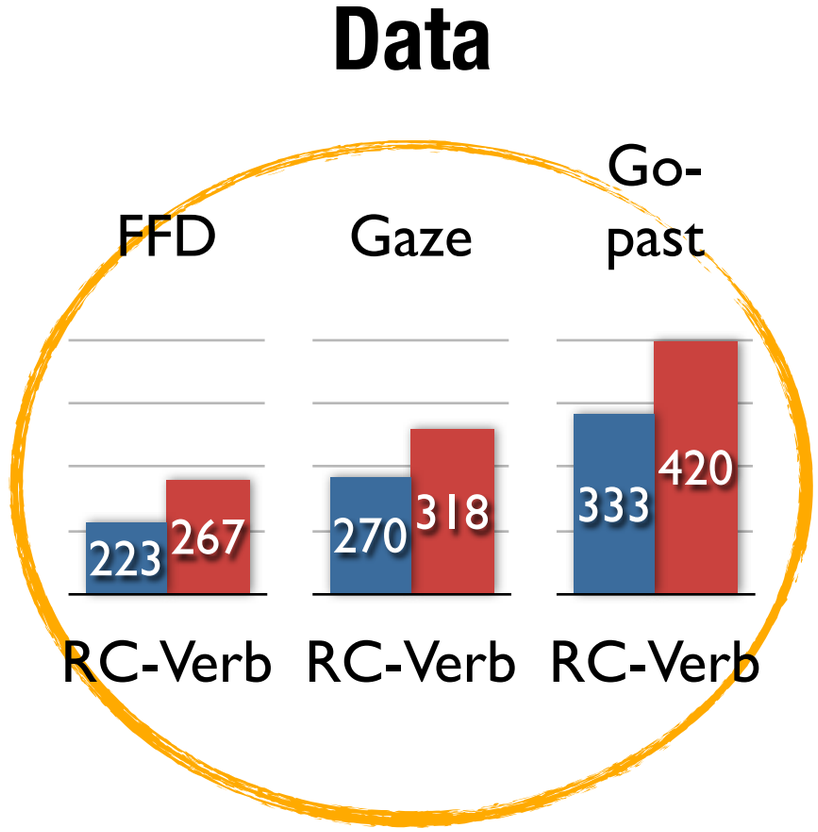
```
(P attach-DP-as-subject-of-predicted-IP-gapped
   =goal>
      ISA               comprehend-sentence
      state             "wm-retrieval"
      goal-cat          VP-gapped-goal
  =retrieval>
      isa               syn-obj
      cat               IP
      head              nil
      subj-word         =subj-word
      waiting-for-cat   wait-for-VP
      spec              =empty-op
      gap               spec
   =lex>
      isa               lexical-entry
      cat               DET
      word              =word
==>
   !bind! =ID-DP (new-name DP)
   =goal>
      state             "wm-retrieval"
      cue1              =empty-op
      attend-to         "left"
  +DPb>
      isa               syn-obj
      cat               DP
      ID                =ID-DP
      case              nom
      head              =word
      spec-of           =retrieval
      waiting-for-case  wait-for-nom
      waiting-for-cat   wait-for-NP
      next-goal         next-VP-gapped-goal
   =retrieval>
      number            sing-plural
      spec              =ID-DP
      gap               open
  +retrieval>
      ISA               syn-obj
      CAT               DP
      ID                =empty-op
      filler            DONE
)
```

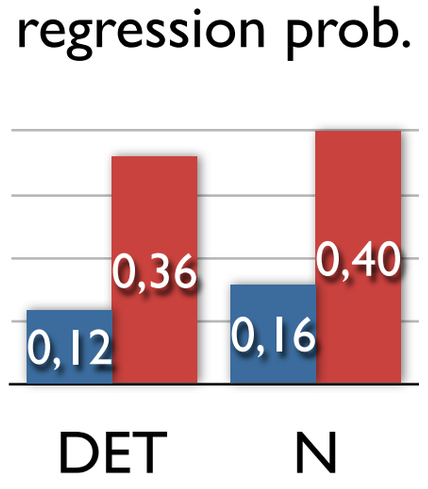
```
(P revise-subject-relative
   =goal>
      ISA               comprehend-sentence
      state             "wm-retrieval"
      goal-cat          VP-gapped-goal
   =retrieval>
      isa               syn-obj
      filler            done
==>
   =goal>
      state             "read"
      goal-cat          NP-goal
      attend-to         "next-word"
   =retrieval>
      ;; reinstate filler as active
      filler            yes-filler
  !eval! (set-end-time)
)
```



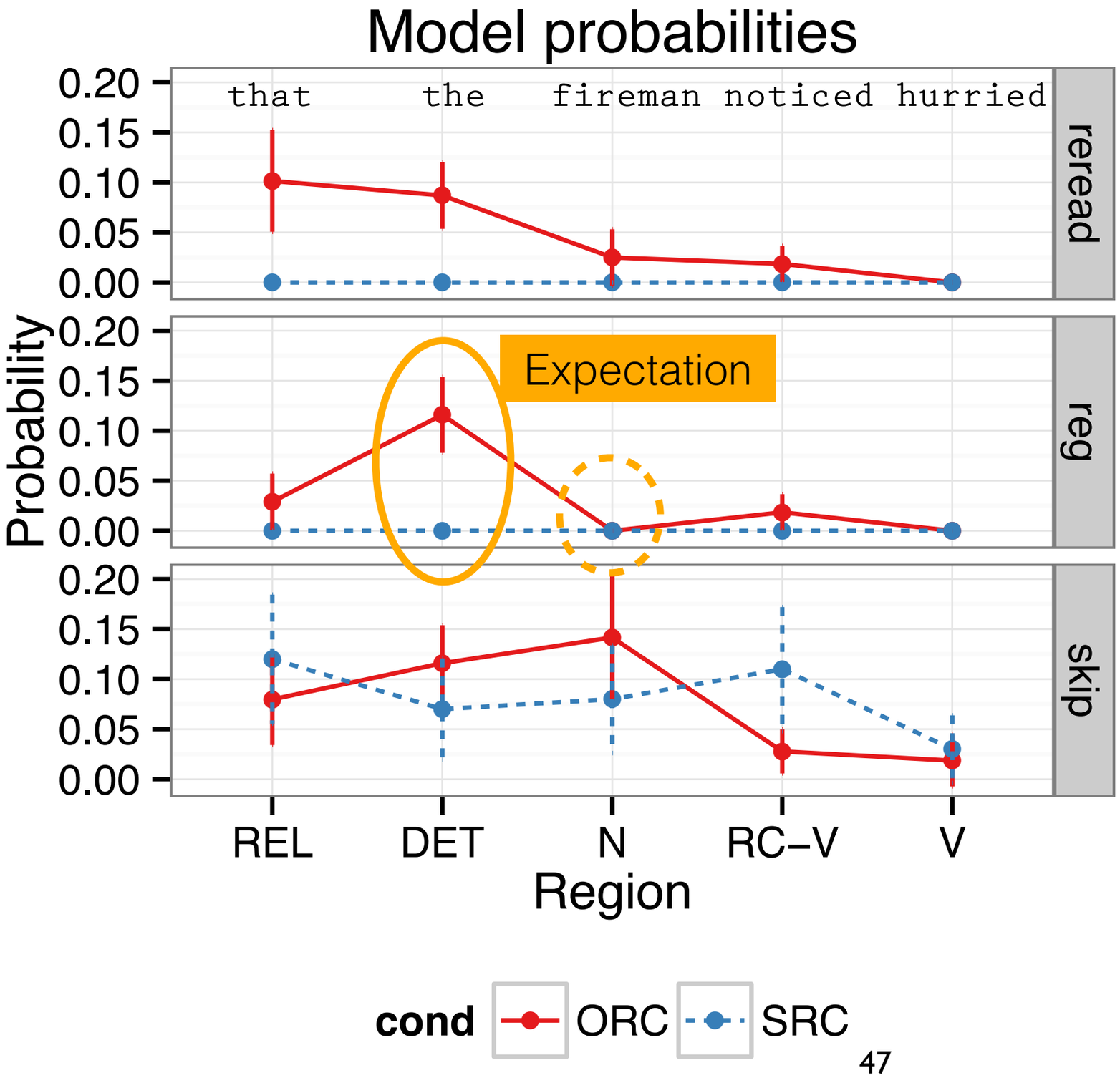
Staub (2010)

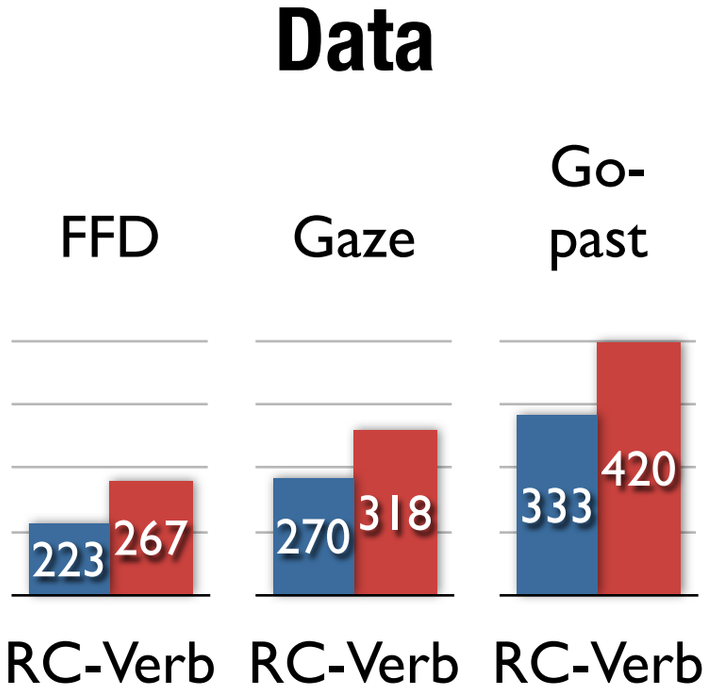

Model reading times
that
the
fireman
noticed
hurried
Memory
FFD
Gaze
Go–past
Mean duration in ms
300
250
200
150
REL
DET
N
RC–V
V
Region
cond
ORC
SRC

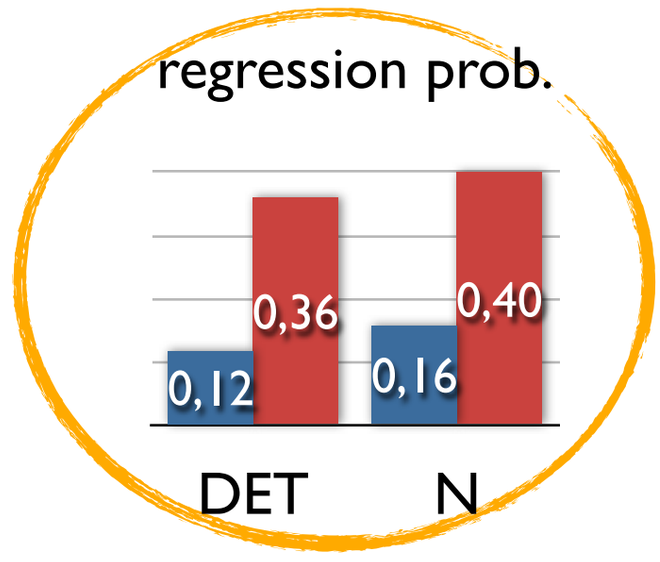

Data
FFD
Gaze
Go-past
223
267
270
318
333
420
RC-Verb
RC-Verb
RC-Verb


regression prob.
0,12
0,36
0,16
0,40
DET
N

Staub (2010)

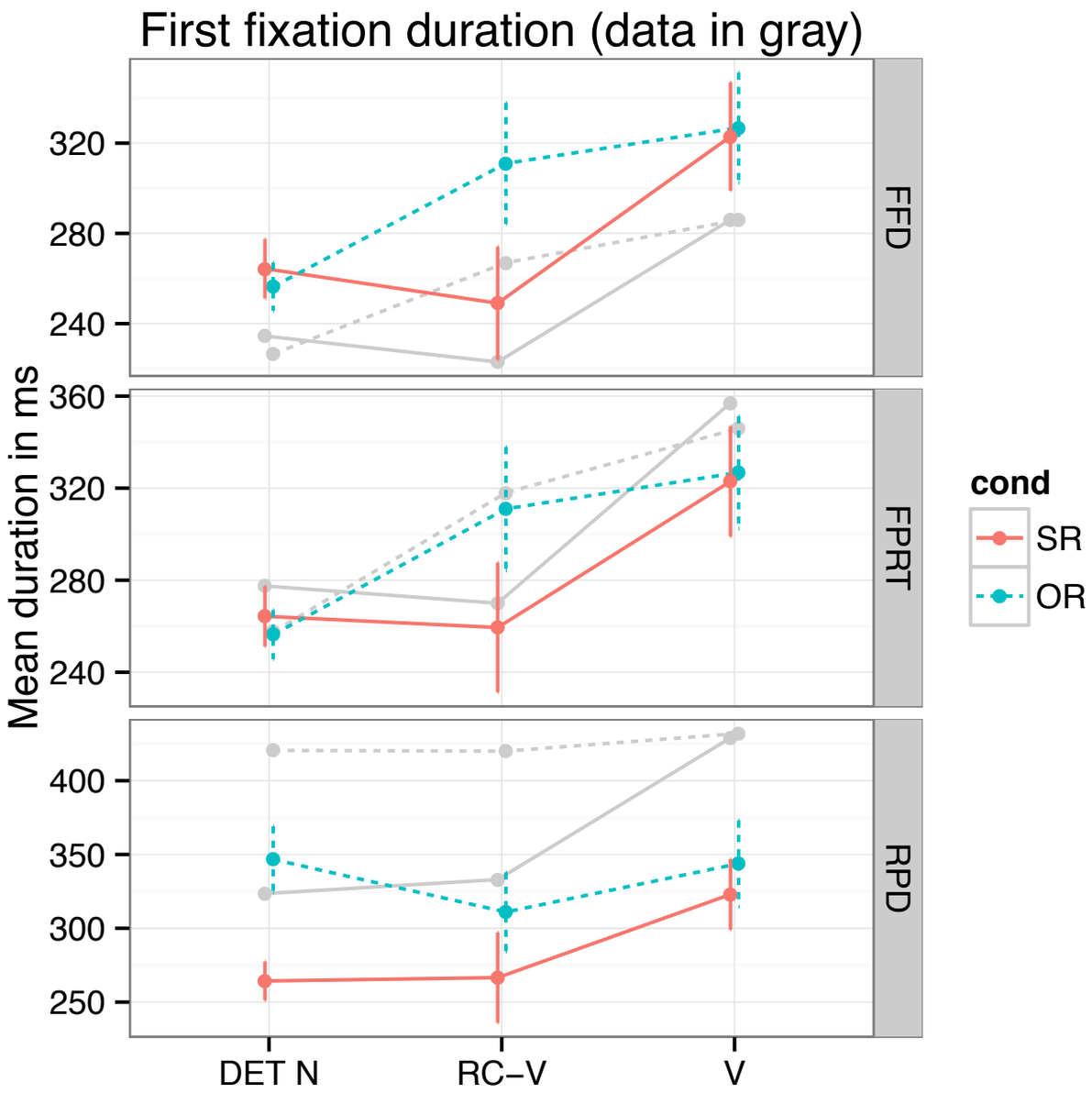

Model probabilities
that the fireman noticed hurried
reread
regress
skip
0.20
0.15
0.10
0.05
0.00
Probability
Expectation
REL
DET
N
RC–V
V
Region
cond
ORC
SRC

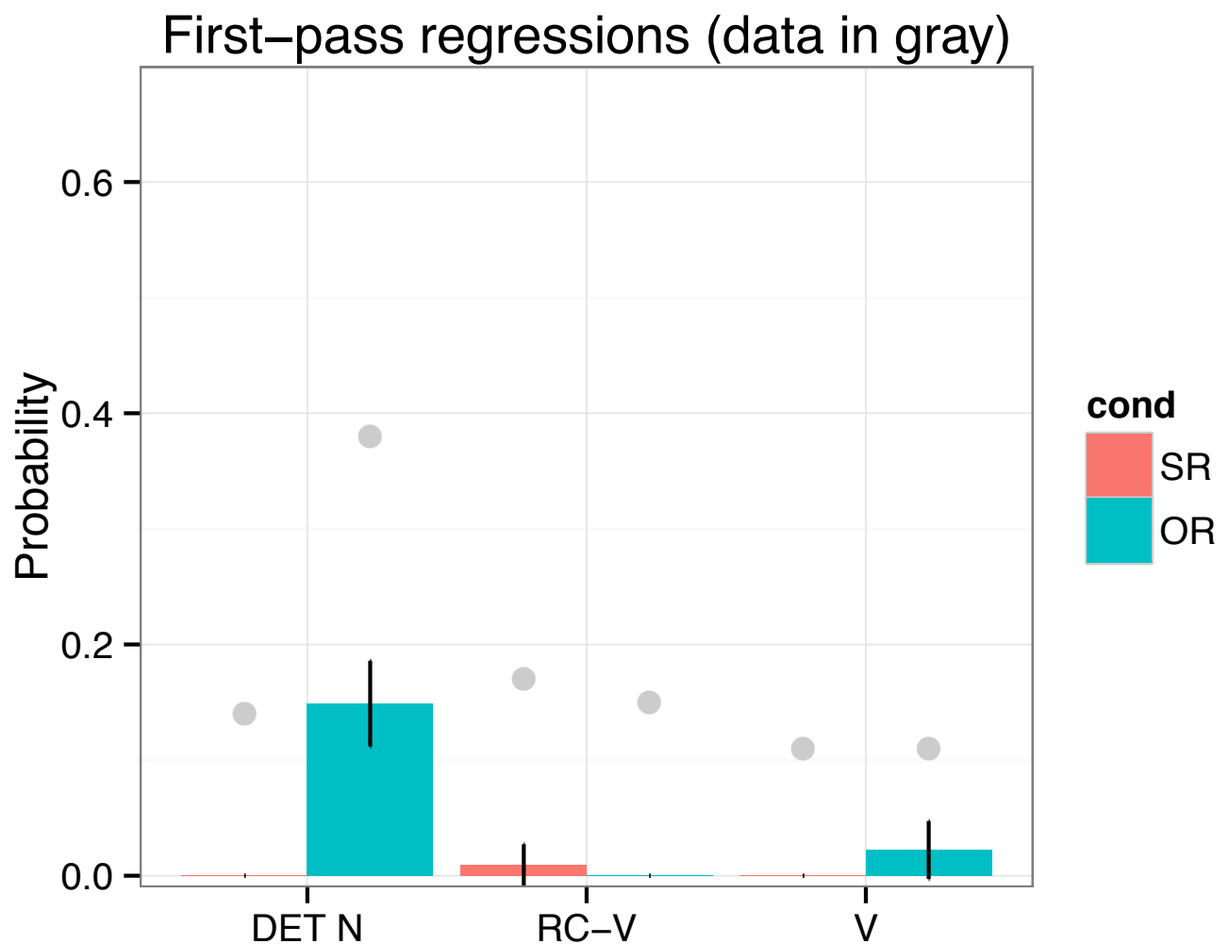

Data
FFD
Gaze
Go-past
223
267
270
318
333
420
RC-Verb
RC-Verb
RC-Verb


regression prob.
0,12
0,36
0,16
0,40
DET
N

Staub (2010)

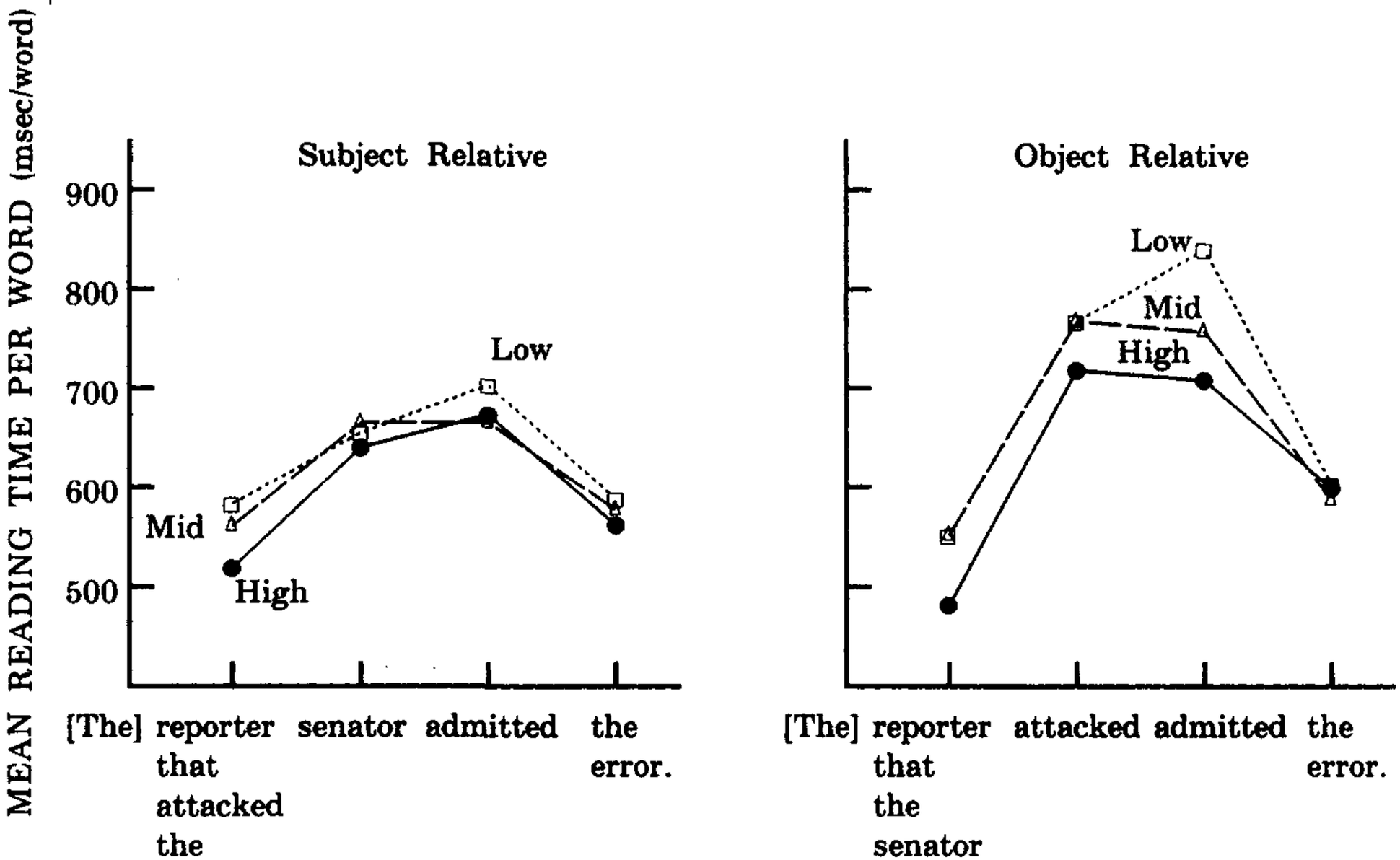
```
(re 'staub10 100)
(cwd "output/")
(run-program "Rscript" '("staub10-analysis.R"))
(cwd "../")
```





Individual Differences

Just and Carpenter (1992): Theory of linguistic working memory capacity. King & Just (1991) showed that WMC as measured by the reading span task (Daneman & Carpenter, 1980) affects sentence comprehension:



Modeling Individual Differences

Latency factor F (:lf) **—> Speed**	$RT = Fe^{-(f*A_i)}$
Decay parameter d (:bll) **—> Speed, forgetting**	$B_i = \ln(\sum_{j=1}^{n} t_j^{-d}) + \beta_i$
Source activation W_k of buffer k (e.g., goalbuffer :ga) This activation is distributed among goal-related chunks. **—> Accuracy (goal-relevant), speed**	$A_i = B_i + S_i + P_i + \varepsilon_i$ $S_i = \sum_k \sum_j W_{kj} S_{ji}$
Mismatch penalty P (:mp) **—> Error sensitivity**	$P_i = \sum_k PM_{ki}$
Similarity M_{ki} between the value k in the retrieval specification and the value in the corresponding slot of chunk i **—> Association between cue and target**	

Working Memory Capacity

Goal buffer source activation W: The amount of activation from source j in the goal buffer is the source activation W divided by the number of sources j in that buffer.

!!! This means that activation spread is less when there are more slots in the goal buffer (filled slots, those with nil do not count) !!!

$$A_i = B_i + \sum_{j=1}^{n} \frac{W}{n} S_{ji}$$

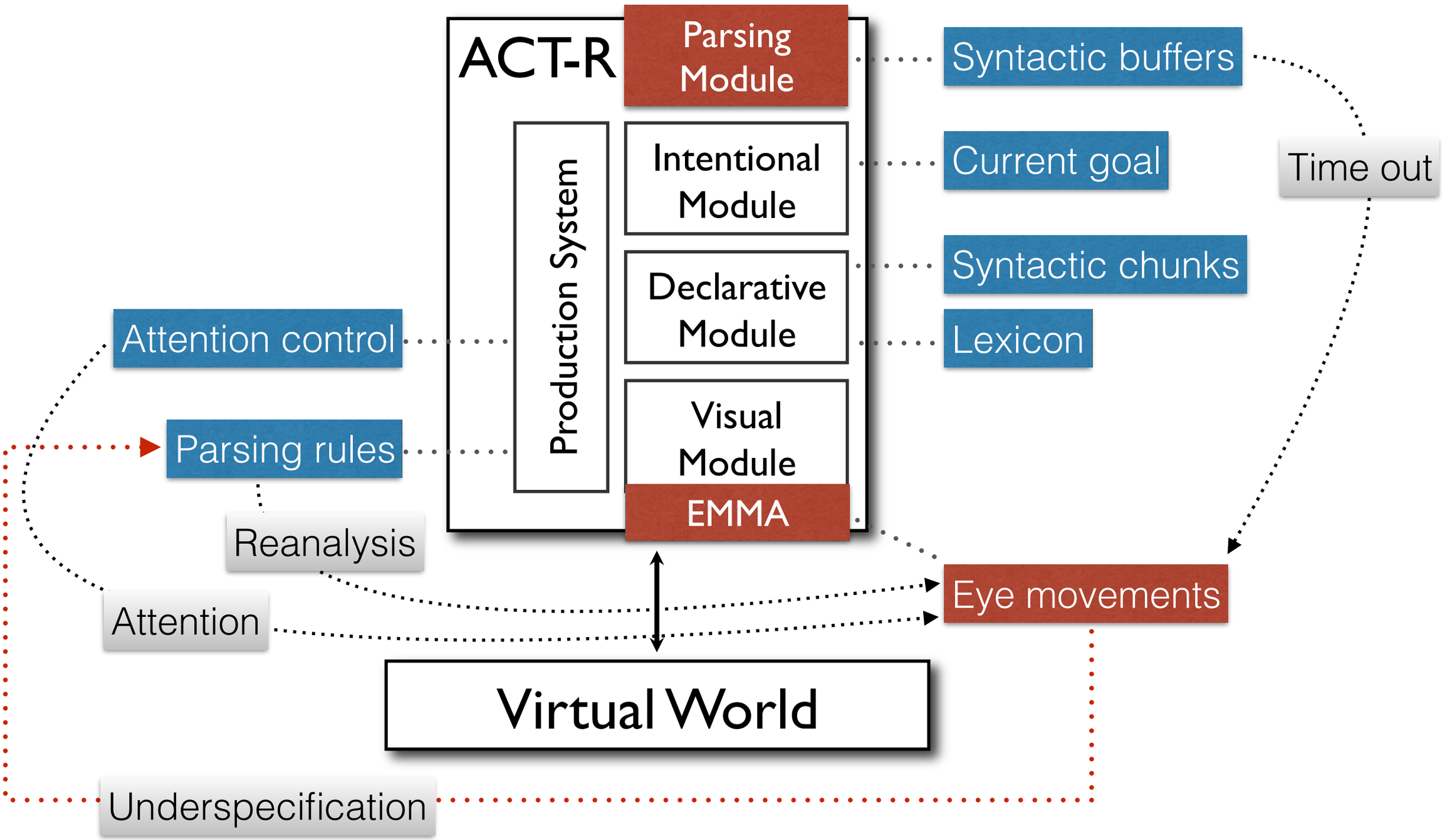
An ACT-R model of WM (Digit span task, Lovett et al., 1999):

Daily, L. Z., Lovett, M. C., & Reder, L. M. (2001). Modeling individual differences in working memory performance: A source activation account. Cognitive Science, 25(3), 315–353.

WM modeled in language processing:

van Rij, J., van Rijn, H., & Hendriks, P. (2013). How WM load influences linguistic processing in adults: A computational model of pronoun interpretation in discourse. Topics in Cognitive Science.

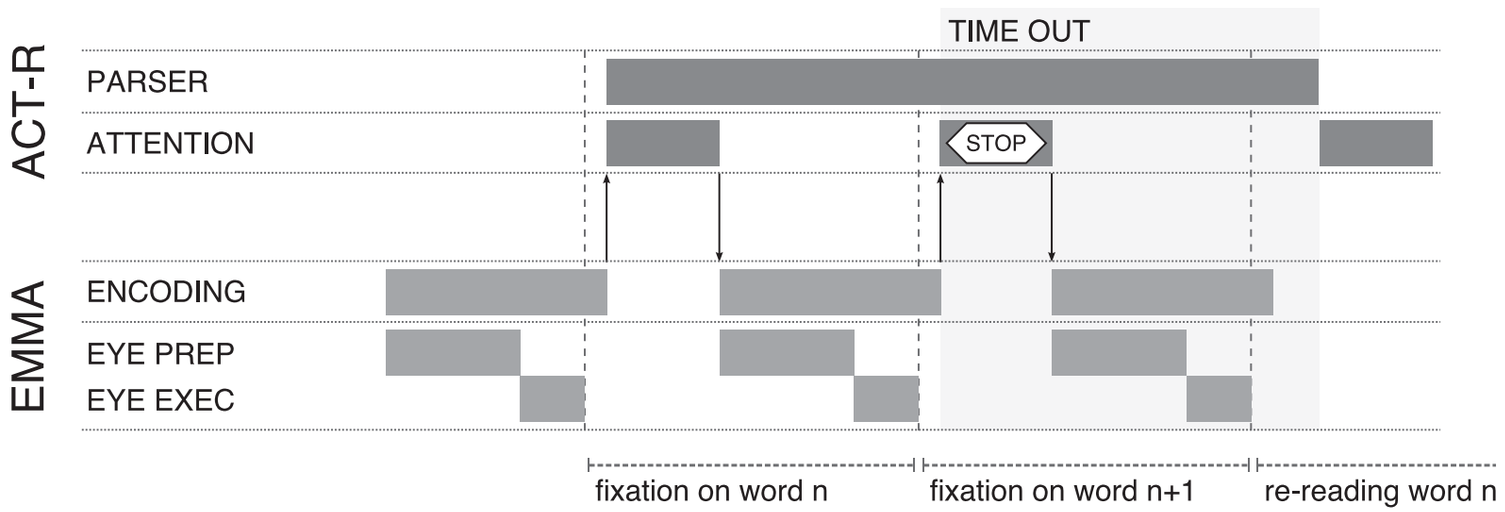
Underspecification Model



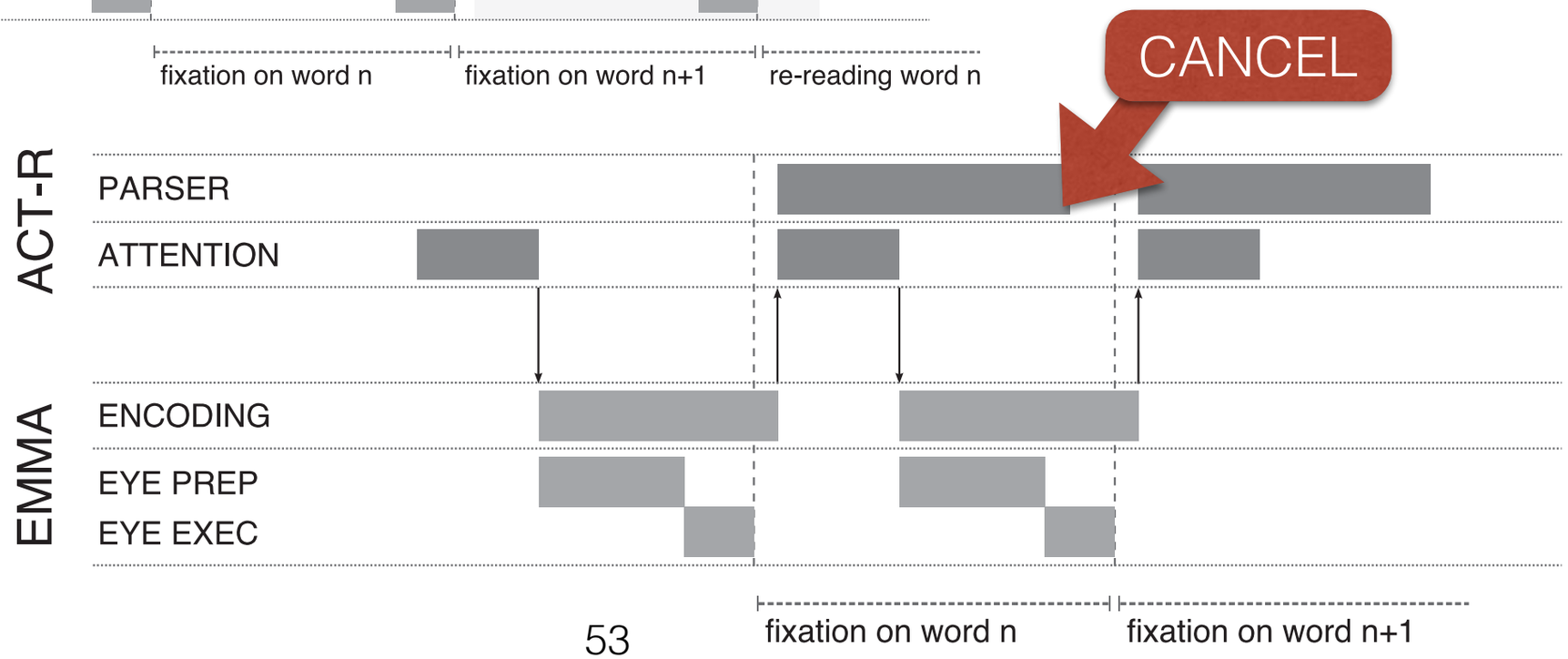
Underspecification Model

Some dependency relations are less important for the current task than others and might stay incomplete under time pressure. The time pressure in reading is imposed by the eye movement control system. The mechanism producing underspecification is the same as for Time Outs regressions:

Time Out



Under-specification

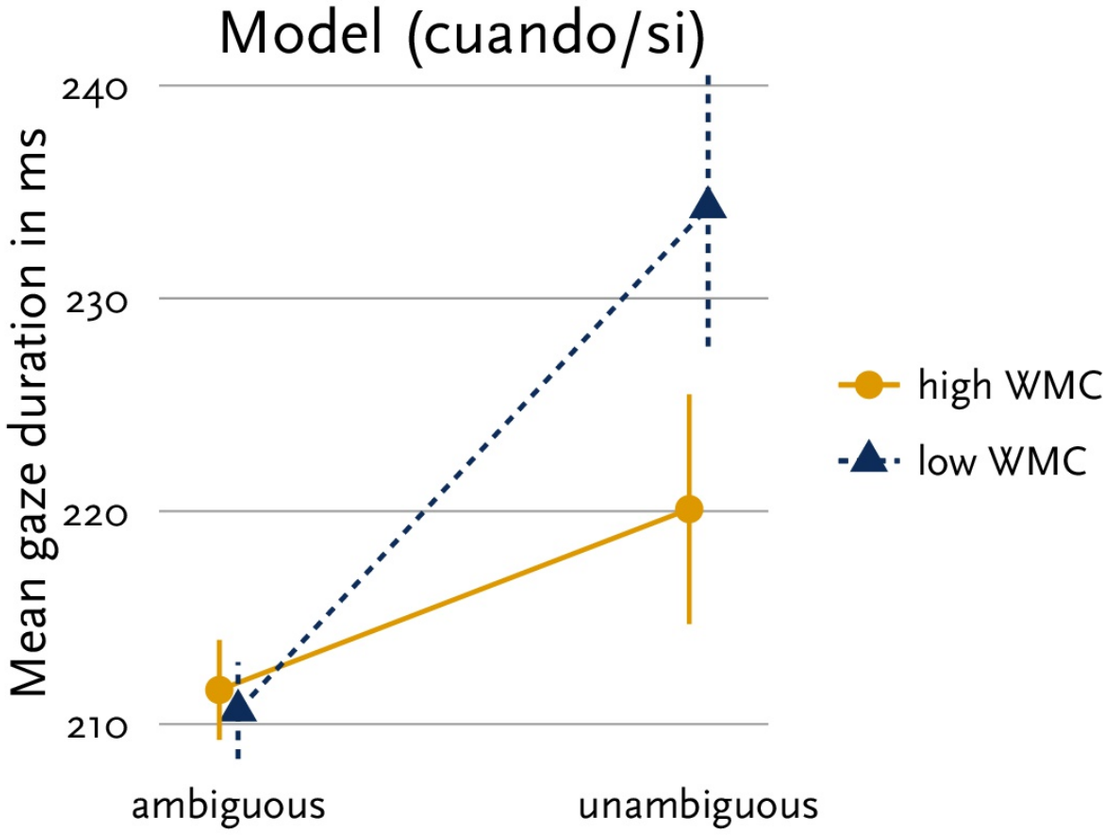


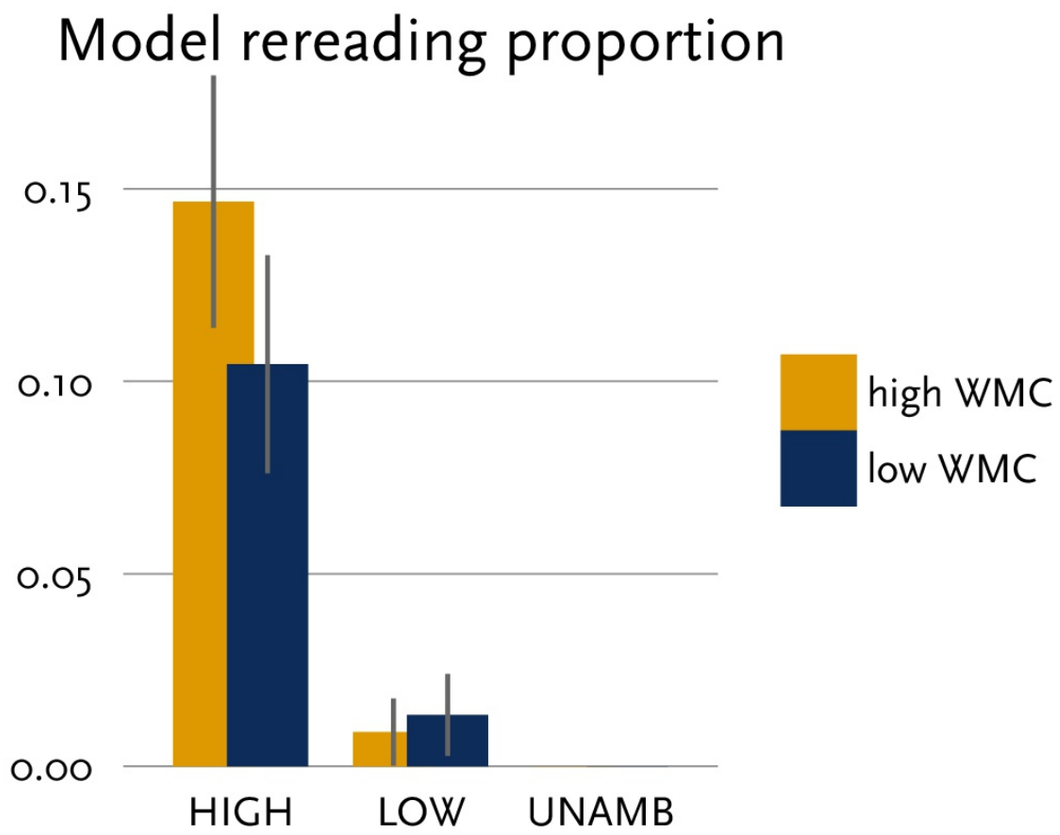
Underspecification Model

The difference to the Time Out mechanism is that, with underspecification, the eye movement proceeds uninterrupted.

Swets et al. (2008):
“According to construal [Frazier & Clifton, 1996], syntactic relations can be divided into primary and secondary types. Whereas **primary relations (roughly, arguments)** are immediately attached […], **secondary relations (roughly, adjuncts)**, including relative clauses and other modifiers initially are indeterminately ‘associated’ with the current thematic domain, at which point other information can be called upon to resolve the association into a determinate attachment.“

The rate of underspecification is affected by **task demands** like the type of comprehension questions (Swets et al., 2008) and by **working memory capacity** (von der Malsburg & Vasishth, 2012).





Von der Malsburg & Vasishth (2012)

reanalysis for high-capacity readers

El profesor dijo que los alumnos se levantaran del asiento...

The teacher said that the students had to stand up from their seats...

ambiguity advantage for low-capacity readers

a. ***cuando*** *los directores* ***entraron*** *en la clase de musica.* — HIGH attachment

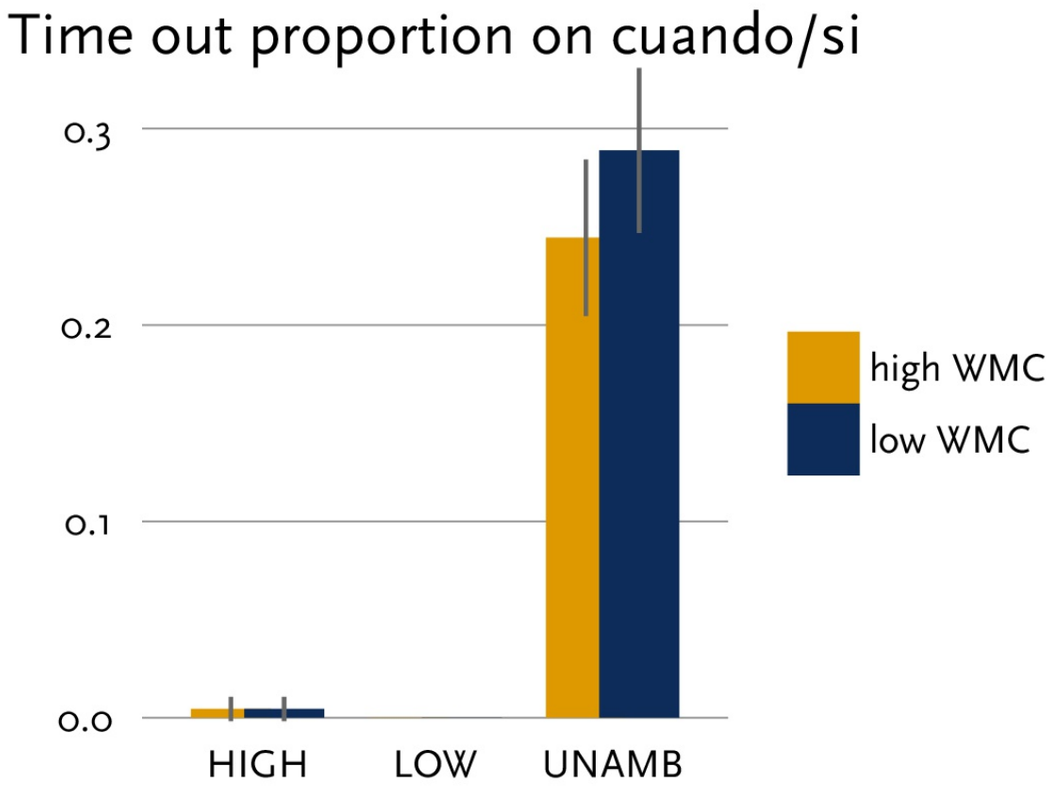
when the directors **came** into the class.

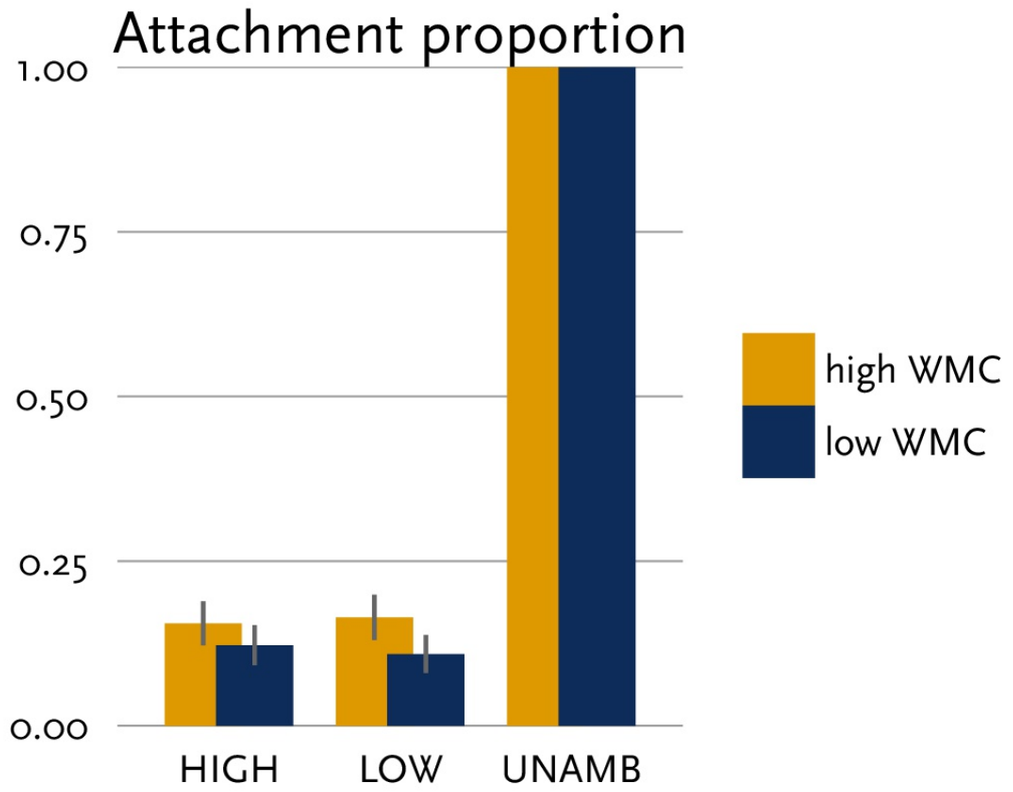
b. ***cuando*** *los directores* ***entraran*** *en la clase de musica.* — LOW attachment

when the directors **come** into the class.

c. ***si*** *los directores* ***entraban*** *en la clase de musica.* — UNAMB (low)

if the directors **come** into the class.





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when the directors **come** into the class.

c. ***si*** *los directores* ***entraban*** *en la clase de musica.* — UNAMB (low)

if the directors **come** into the class.

Modeling Individual Subjects

Run subjects

10 iterations, 5 subjects: `(res 'gg-exp1 10 5)`

For each subject, goal activation W is drawn from a normal distribution with mean = 1 and standard deviation = 0.25.

Parameter estimation

```
(setf *paramspace* '((:lf .2 .4 .1)
                     (:mp 1.5 2 .5)))

(search-param-space-em gg-exp1 5 *paramspace*)

(search-param-space-subjects-em gg-exp1 5 3 *paramspace*)
```

Parsing Module

Parallel retrieval

Two new retrieval buffers that wok in parallel:

GRAMMATICAL>
LEXICAL>

And a context buffer:

CONTEXTUAL>

Chunk creation

STRUCTURAL>
STRUCTURAL2>
STRUCTURAL3>

Parameters

Force-merge merges modified chunk copies back with their originals.

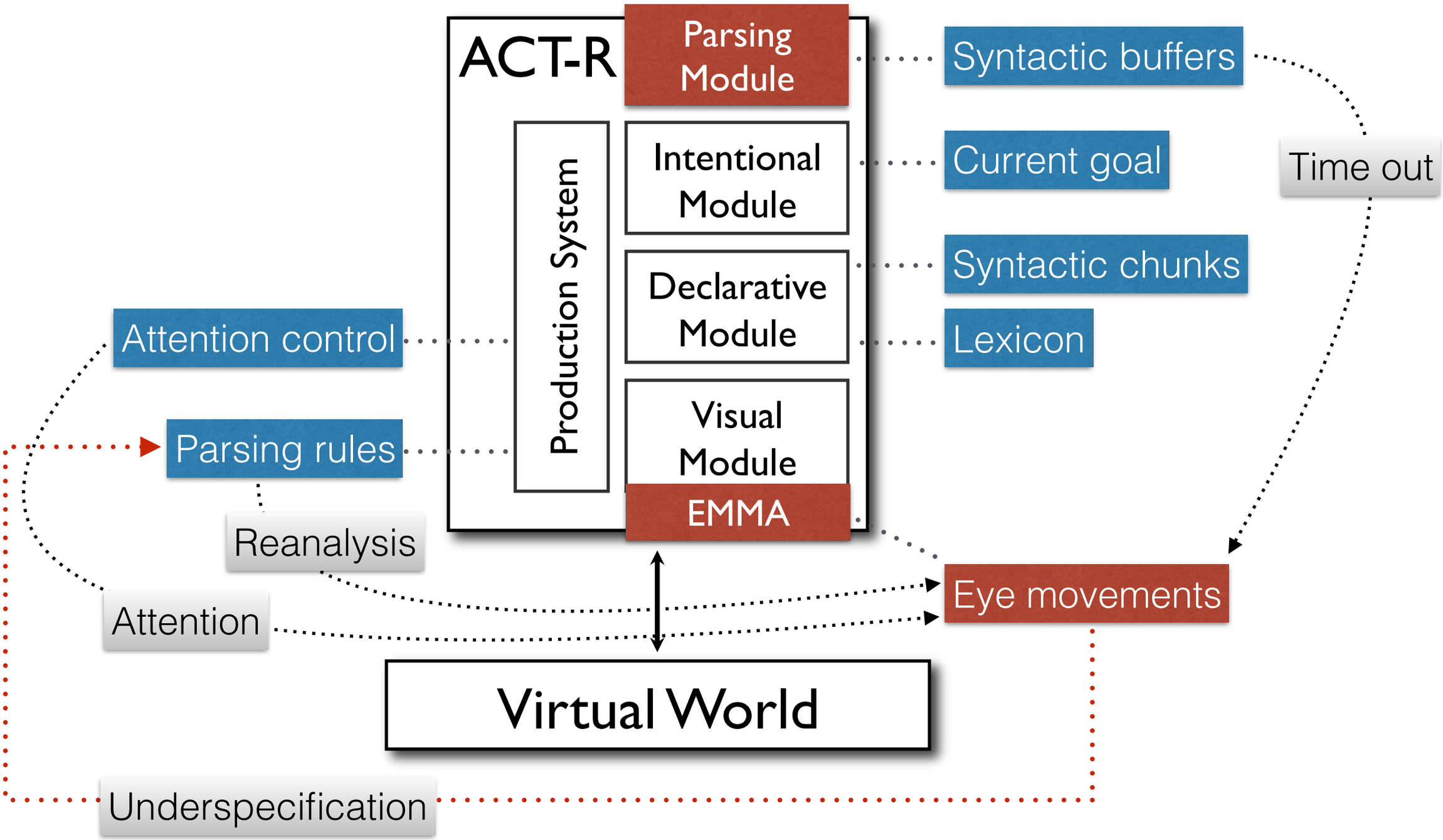
```
+grammatical>
      ISA                  syn-obj
      waiting-for-cat      wait-for-NP

+lexical>
      ISA                  lexical-entry
      word                 =word
```

```
+structural>
      ISA                  syn-obj
      cat                  DP
      head                 =word
      spec-of              =grammatical>
```

```
:gram-force-merge T
:gram-lf    :lex-lf
:gram-rt    :lex-rt
```

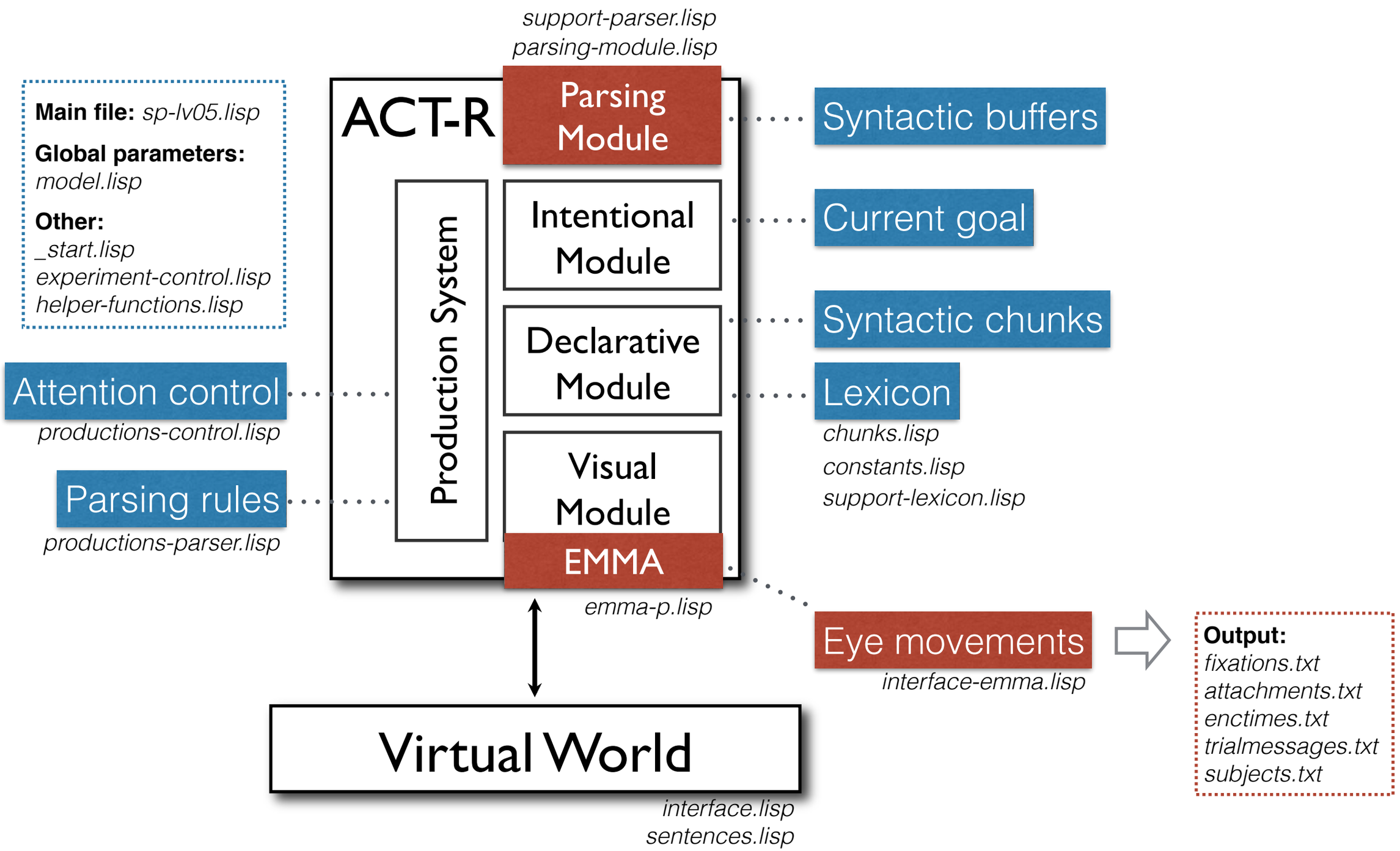
Model Structure

Eye Movement Interaction



Model Structure

File Structure



Function Summary

Run sentence

```
(ps SENTENCE :params PARAMS)  ;; single presentation
(rps SENTENCE ITERATIONS :params PARAMS)  ;; repeated presentation
Example: (ps *gg-or* :params '(:lf 0.8))   ;; (params are optional)
Example: (rps "the dog bit the boy *“ 100)

(demo) (demo1) (demo2) (demo3) ;; Run demo sentence
```

Reload model

```
(rl) ;; Reload model
(clear-sp) ;; Reload all files
```

Run experiment (with individual subjects)

```
(re NAME ITERATIONS :params PARAMS)
Example: (re 'gg-exp1 50 :params '(:lf 0.8 :mp 2)) ;; (params are optional)

(res NAME ITERATIONS SUBJECTS :params PARAMS)
Example: (res 'gg-exp1 20 50)
```

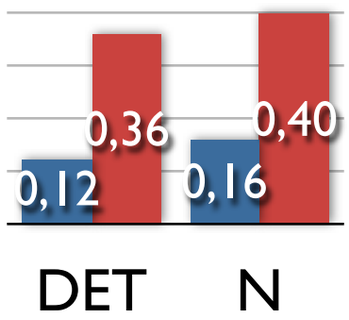
Search parameter space

```
(search-param-space-em EXPERIMENT ITERATIONS PSPACE)

(search-param-space-em EXPERIMENT ITERATIONS SUBJECTS PARAMSPACE)
Example: (search-param-space-subjects-em gg-exp1 20 50 *paramspace1*)
```

Possible Extension:

The Articulatory Loop

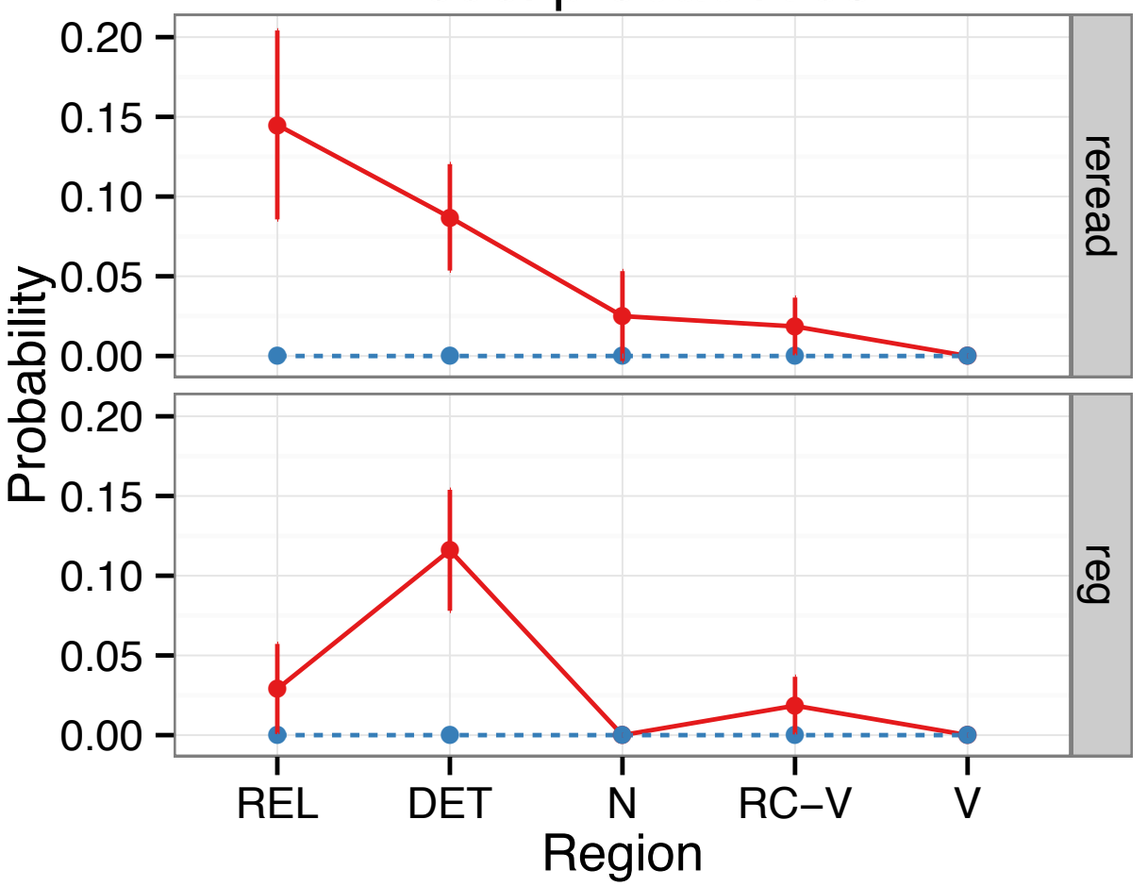
Data FP-Regr



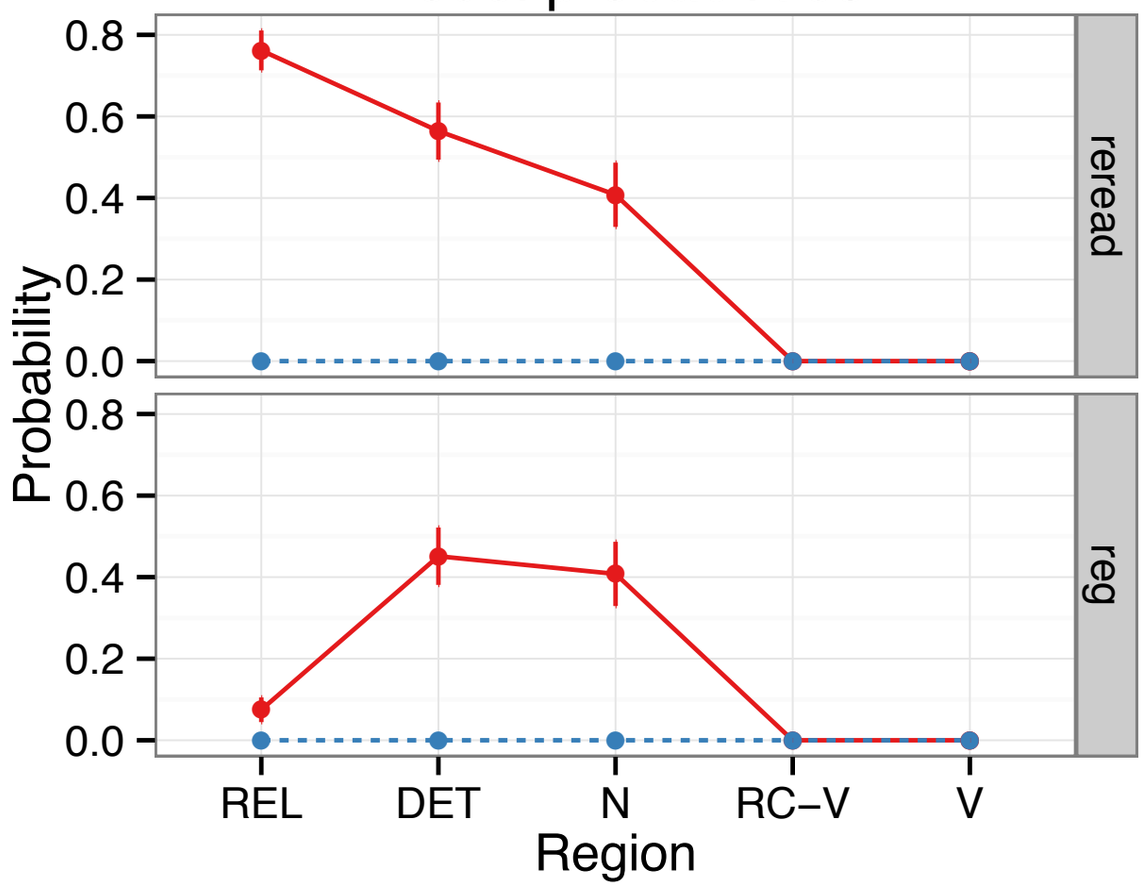
Articulatory Loop

Staub (2010) revisited

Without loop



With loop



Articulatory Loop

```
(p subvocalize
    =goal>
       ISA             comprehend-sentence
       state           "wm-retrieval"
       em-state        "attending"
    =visual>
       ISA             text
       value           =word
   ?vocal>
       preparation     free
 ==>
    =goal>
       em-state        "free"
    +vocal>
       ISA             subvocalize
       string          =word
 )

(p attend-subvocalized-word …)
(p lexical-retrieval-request-of-subvocalization …)
```

Articulatory Loop

Predictions:

- Delayed effects of parsing depend on articulatory loop
- In some cases retrieval not necessary because two words can be integrated in one step
- „Wrap-up effects“ at phrasal boundaries due to clearing the loop (especially when storing more than one word)

Questions:

- How to decide between Time Out and Loop?
- How many words to store? (Decide based on structural expectations?)

➡ **Run experiments with blocking subvocalization**

Class Projects

Individual differences in relative clause processing

King & Just (1991); Just & Carpenter (1992)

Locality effects in eye tracking

Grodner & Gibson (2005) Exp. 2 replicated in eye tracking by Bartek, Lewis, Vasishth & Smith (2011)

Negative polarity intrusion with eye movements

Vasishth, Brüssow, Lewis & Drehhaus (2008)

Scalar implicatures and working memory

Bott & Noveck (2004)