

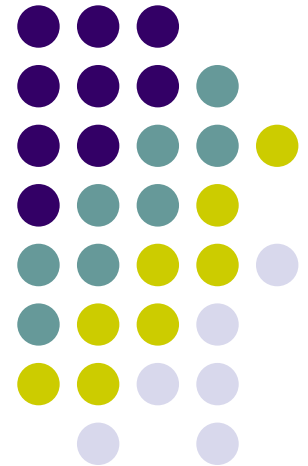
The time-course of anaphoric processing and syntactic reconstruction

Akira Omaki, Christopher Dyer,
Shiti Malhotra, Jon Sprouse,
Jeffrey Lidz, and Colin Phillips

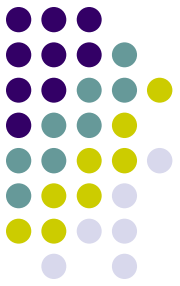
University of Maryland



20th annual CUNY conference on sentence processing
March 29th, 2007



Goals of the study



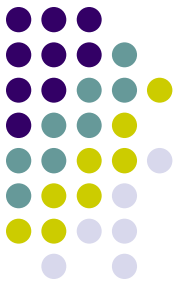
1. To investigate whether grammar guides the process of antecedent search for anaphora in a more complicated construction
2. To resolve a puzzle raised by research on children's interpretation of reflexives embedded in a wh-phrase

Anaphoric dependencies in language comprehension



- Anaphoric expressions in natural language
 - John believes he is a genius
 - John believes himself to be a genius

Anaphoric dependencies in language comprehension



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 - **Mary** forgot the keys when she left

Anaphoric dependencies in language comprehension



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 - **Mary** forgot the keys when she left [backward search]

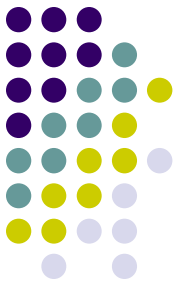


Anaphoric dependencies in language comprehension



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 - **Mary** forgot the keys when she left [backward search]
 - When she left, **Mary** forgot the keys.

Anaphoric dependencies in language comprehension



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 - **Mary** forgot the keys when she left [backward search]
 - When she left, **Mary** forgot the keys. [forward search]

Roadmap



1. Background and motivations
 - Restricting backward and forward search: syntactic reconstruction
 - Reflexive resolution in children: A missing reading
2. Restricting the backward search (Exp 1a, 1b)
3. Restricting the forward search (Exp 2)
4. Discussion

Structural constraints on anaphora resolution



- Reflexives in English
 - Mary believes [that Bill kicked **himself**]

Reflexives must be bound in a local domain
(i.e., within the same clause) (Chomsky, 1981)

Structural constraints on anaphora resolution



- Reflexives in English

- Mary believes [that Bill kicked himself] 😊



Accessible

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Structural constraints on anaphora resolution



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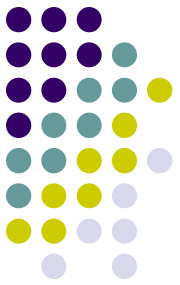


Accessible

- Bill believes [that Mary kicked himself]

Reflexives must be bound in a local domain (i.e., within the same clause) (Chomsky, 1981)

Structural constraints on anaphora resolution



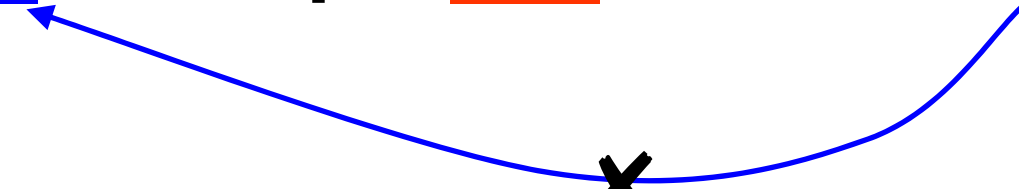
- Reflexives in English

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Accessible

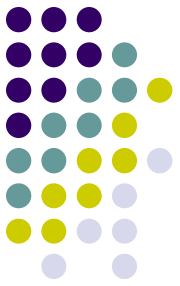
- Bill believes [that Mary kicked himself] ☹️



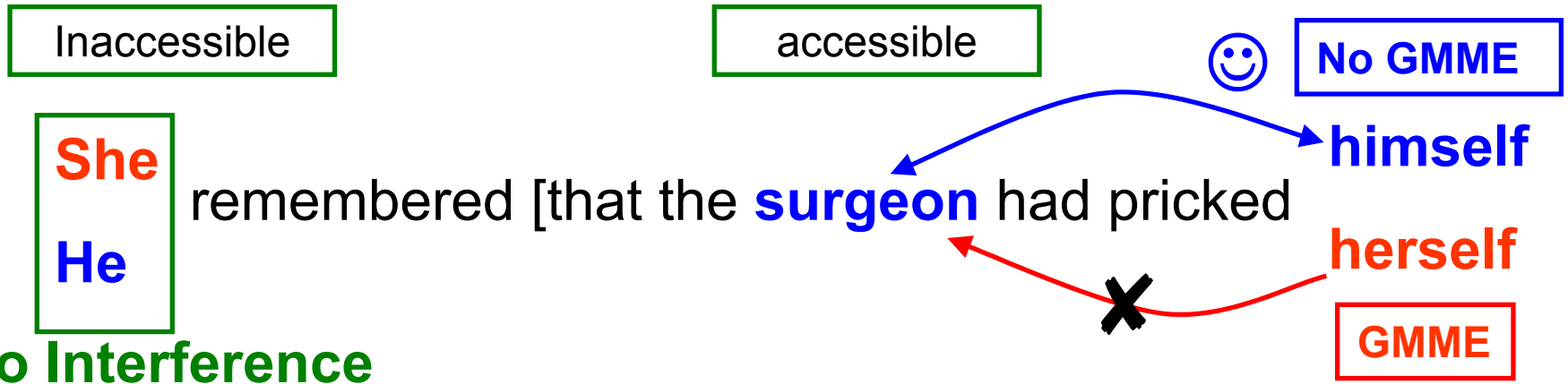
Inaccessible

Reflexives must be bound in a local domain (i.e., within the same clause) (Chomsky, 1981)

Structural constraints on anaphora resolution



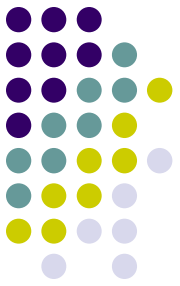
- Start 2003



Structural constraints guide backward search for antecedents

cf. Badecker & Straub 2002, Nicol & Swinney 1989,
Runner, Sussman & Tanenhaus 2006, *inter alia*

Forward antecedent searches and prediction



- Forward search for antecedent:
(Kazanina et al. 2007, Van Gompel & Liversedge 2003)

When **she** ...

Forward antecedent searches and prediction



- Forward search for antecedent:
(Kazanina et al. 2007, Van Gompel & Liversedge 2003)

When **she** was fed up, ...

Forward antecedent searches and prediction



- Forward search for antecedent:
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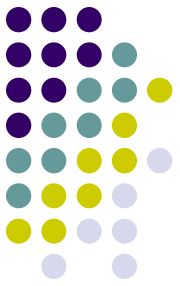


Predictive search

Predictive parser:

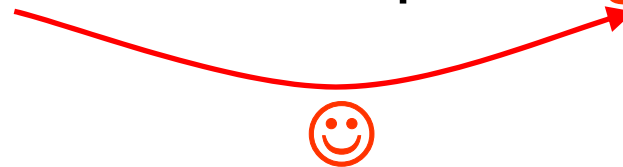
Gibson 1998, Kimball 1973, Konieczny 2000,
Lau et al 2006, Levy 2006

Forward antecedent searches and prediction



- Forward search for antecedent:
(Kazanina et al. 2007, Van Gompel & Liversedge 2003)

When **she** was fed up, the **girl** ...

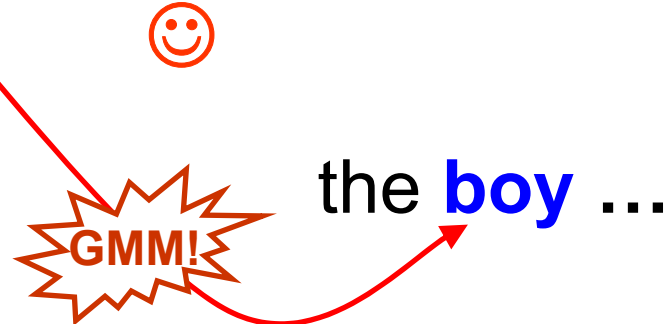


Forward antecedent searches and prediction

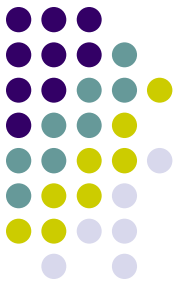


- Forward search for antecedent:
(Kazanina et al. 2007, Van Gompel & Liversedge 2003)

When **she** was fed up, the **girl** ...



Forward antecedent searches and prediction



- Kazanina et al 2007

When **she** ... **Jessica** / **Russell**...



Structurally accessible

She ... **Jessica** / **Russell**...

No GMME

Structurally inaccessible

Grammatical constraints guide forward search

Interaction of wh-movement and anaphoric processing



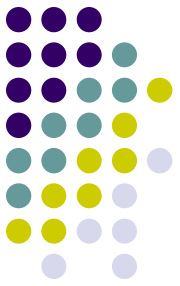
- The studies so far investigated cases where **only one direction** needs to be searched

Interaction of wh-movement and anaphoric processing



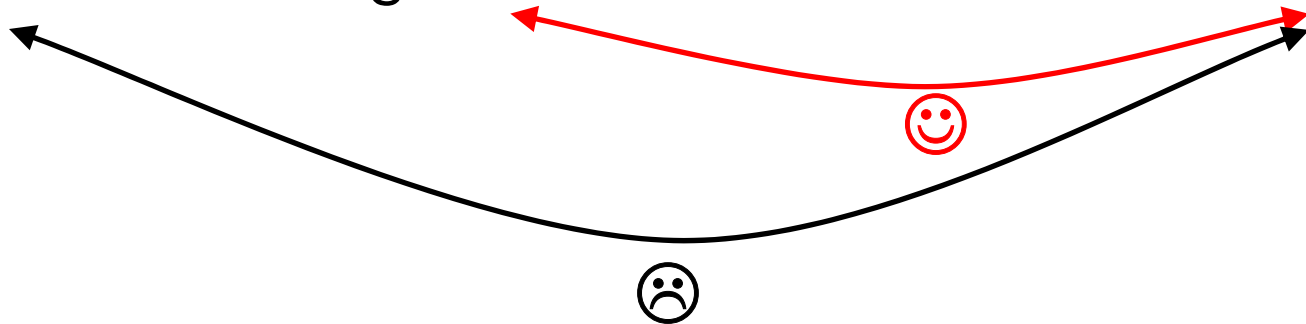
- The studies so far investigated cases where **only one direction** needs to be searched
- much more complicated situation: **Both directions need to be searched in sentences that involve syntactic reconstruction**

Wh-movement and reflexive: Syntactic reconstruction effects

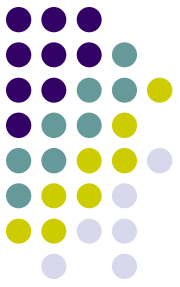


- Anaphors in English

John knew [_S Bill saw a picture of himself.]



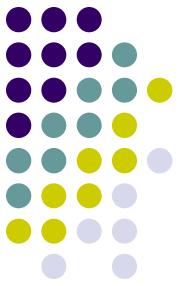
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- Anaphors and ***argument reconstruction***

John knew [_SBill saw a picture of himself.]

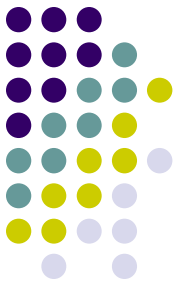
Wh-movement and reflexive: Syntactic reconstruction effects



- Anaphors and *argument reconstruction*

John knew [_SBill saw **which** picture of himself.]

Wh-movement and reflexive: Syntactic reconstruction effects

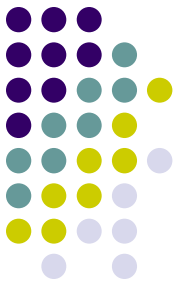


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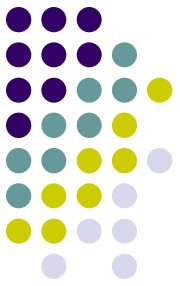
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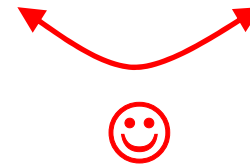
John knew **which** picture of himself [_S Bill saw ___]

Wh-movement and reflexive: Syntactic reconstruction effects

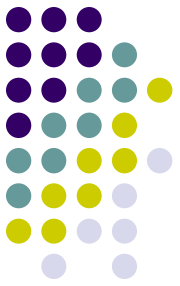


- Anaphors and *argument reconstruction*

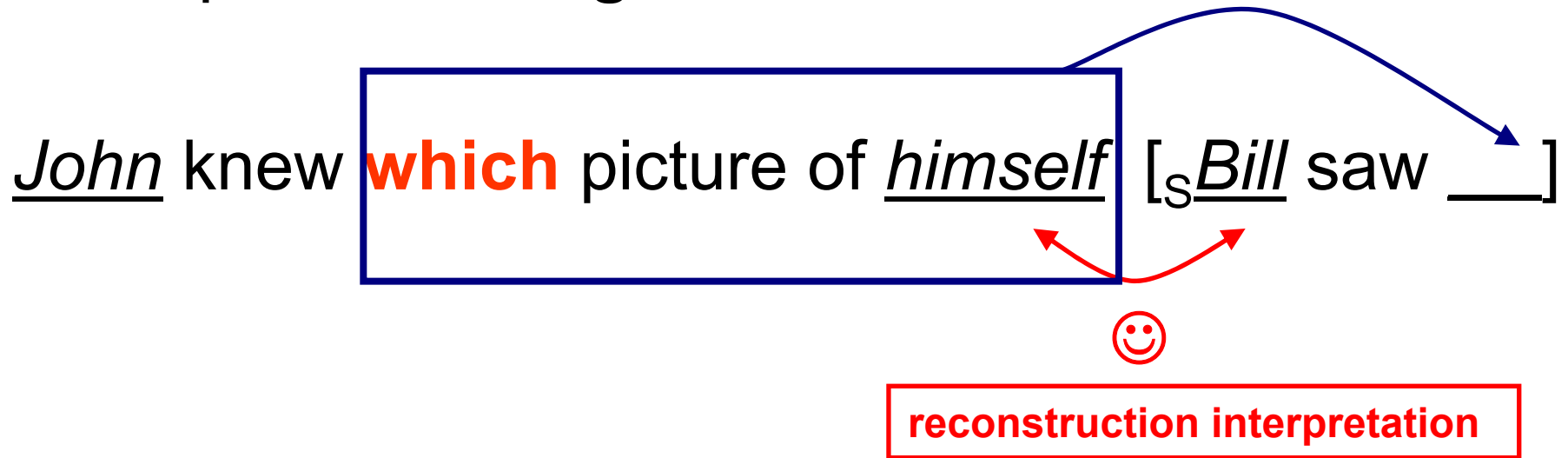
John knew **which** picture of himself [_SBill saw ____]



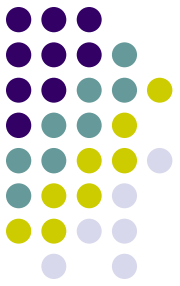
Wh-movement and reflexive: Syntactic reconstruction effects



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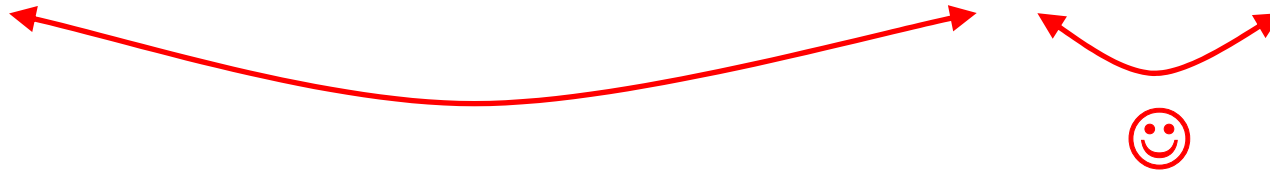


Wh-movement and reflexive: Syntactic reconstruction effects



- Anaphors and *argument reconstruction*

John knew **which** picture of himself [_SBill saw ___]



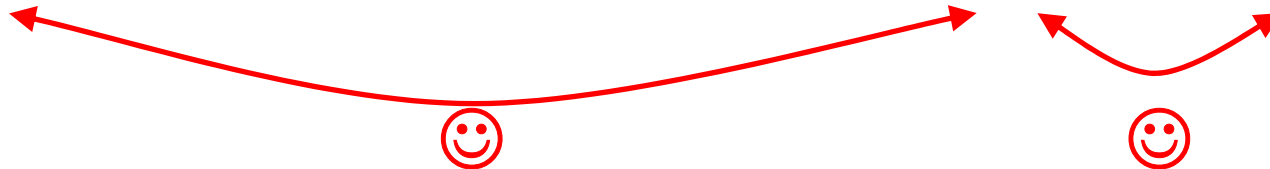
reconstruction interpretation

Wh-movement and reflexive: Syntactic reconstruction effects



- Anaphors and *argument reconstruction*

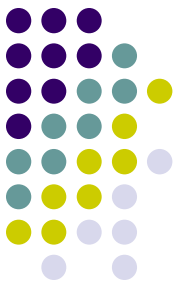
John knew **which** picture of himself [_S Bill saw ___]



surface interpretation

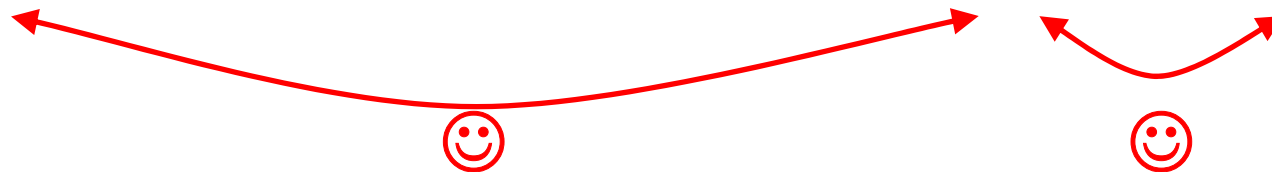
reconstruction interpretation

Wh-movement and reflexive: Syntactic reconstruction effects



- Anaphors and *argument reconstruction*

John knew **which** picture of himself [_SBill saw ___]



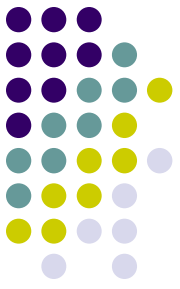
surface interpretation

reconstruction interpretation

1. Wh-fronting of an argument adds an interpretive possibility for the reflexive

(Barss, 1986; Heycock, 1995; Huang, 1993)

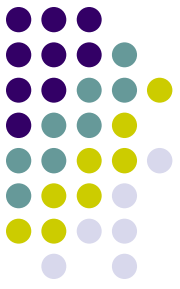
Syntactic reconstruction effects: Argument vs. Predicate fronting



- Anaphors and *predicate reconstruction*

John knew [_SBill was very proud of himself.]

Syntactic reconstruction effects: Argument vs. Predicate fronting



- Anaphors and *predicate reconstruction*

John knew [_SBill was **how** proud of himself.]

Syntactic reconstruction effects: Argument vs. Predicate fronting

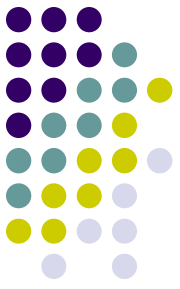


- Anaphors and *predicate reconstruction*

John knew **how** proud of himself [_S Bill was ___]

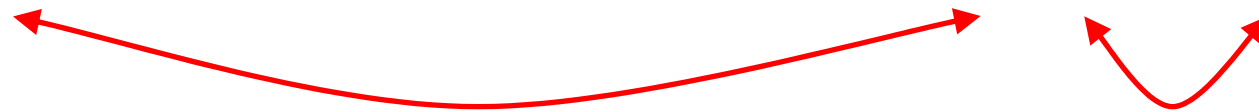
Same wh-movement...

Syntactic reconstruction effects: Argument vs. Predicate fronting



- Anaphors and *predicate reconstruction*

John knew **how** proud of himself [_S Bill was ___]



~~surface interpretation~~

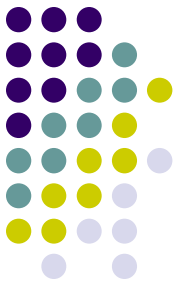


reconstruction interpretation

**2. Wh-fronting of a predicate adds NO
interpretive possibility for the reflexive**

(Barss, 1986; Heycock, 1995; Huang, 1993)

Syntactic reconstruction effects: Argument vs. Predicate contrast



Argument

John knew **which** picture of himself [Bill saw ____]

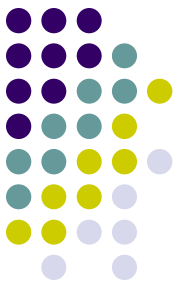
surface interpretation

reconstruction interpretation

Predicate

John knew **how** proud of himself [Bill was ____]

reconstruction interpretation



Off-line acceptability (7-point scale)

Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

5.69 / 7

reconstruction interpretation

5.67 / 7

Predicate

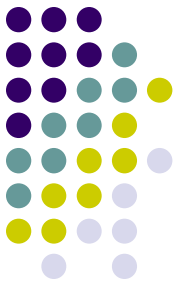
John knew **how** proud of himself [Bill was ___]

2.31 / 7

reconstruction interpretation

5.39 / 7

Time-course of reflexive resolution



Argument

John knew **which** picture of **himself** [Bill saw ___]

Predicate

John knew **how** proud of **himself** [Bill was ___]

Time-course of reflexive resolution

Argument fronting



Argument

John knew **which** picture of **himself** [Bill saw ___]



Predicate

John knew **how** proud of **himself** [Bill was ___]

Time-course of reflexive resolution

Argument fronting



Argument

John knew **which** picture of **himself** [Bill saw ___]

surface interpretation

INITIAL interpretation

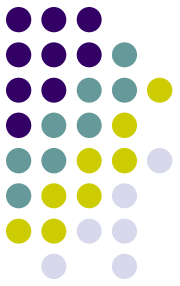
(Immediate forward anaphor resolution: Nicol & Swinney, 1989; Sturt 2003)

Predicate

John knew **how** proud of **himself** [Bill was ___]

Time-course of reflexive resolution

Argument fronting



Argument

John knew **which** picture of **himself** [Bill saw ___]

surface interpretation

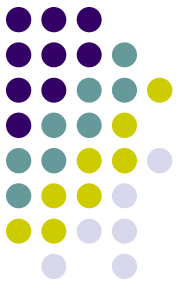
INITIAL interpretation

Predicate

John knew **how** proud of **himself** [Bill was ___]

Time-course of reflexive resolution

Argument fronting



Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

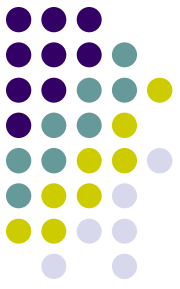
SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

Time-course of reflexive resolution

Predicate fronting



Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

Time-course of reflexive resolution: Predicate fronting



Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

Surface interpretation
should be blocked

Time-course of reflexive resolution: Predicate fronting



Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

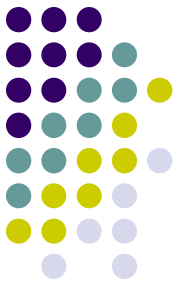
SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

Forward search

Time-course of reflexive resolution: Predicate fronting



Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

reconstruction interpretation

INITIAL interpretation

Time-course of reflexive resolution: Predicate fronting



Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

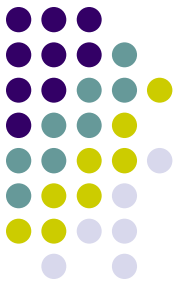
John knew **how** proud of himself [Bill was ___]

reconstruction interpretation

INITIAL interpretation

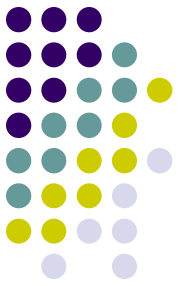
Does the parser actually
behave this way?

Leddon & Lidz 2005: Children's reconstruction effects



- Children's knowledge of **argument vs. predicate asymmetry** in syntactic reconstruction effects

Leddon & Lidz 2005: Children's reconstruction effects



- Children's knowledge of **argument vs. predicate asymmetry** in syntactic reconstruction effects

Truth Value Judgment Task (offline)

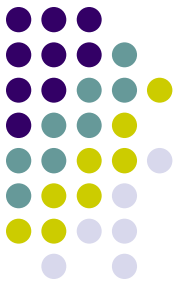
Argument

Miss Cruella figured out which picture of **herself Janie** put up.

Predicate

Mr. Monkey figured out how proud of **himself Andy** was.

Children's behavior: Argument vs. Predicate contrast



Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

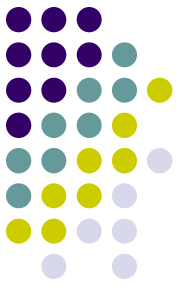
No!



reconstruction interpretation

INITIAL interpretation

Children's behavior: Argument vs. Predicate contrast



Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

No!



YES!



reconstruction interpretation

INITIAL interpretation

Children's behavior: Argument vs. Predicate contrast



Argument

John knew **which** picture of himself [Bill saw ___]

YES!



surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

No!



reconstruction interpretation

INITIAL interpretation

YES!



Children's behavior: Argument vs. Predicate contrast



Argument

NO WAY!



John knew **which** picture of himself [Bill saw ___]



surface interpretation
INITIAL interpretation

~~reconstruction interpretation~~
~~SECOND interpretation~~

Predicate

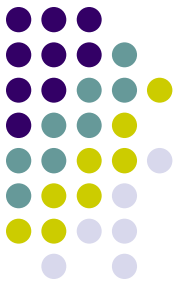


John knew **how** proud of himself [Bill was ___]



reconstruction interpretation
INITIAL interpretation

Children's behavior: Argument vs. Predicate contrast



Argument

Reanalysis is hard
(Trueswell et al 1999)



John knew **which** picture of himself [Bill saw ___]

YES!



surface interpretation

INITIAL interpretation

~~reconstruction interpretation~~

~~SECOND interpretation~~

Predicate

John knew **how** proud of himself [Bill was ___]

No!



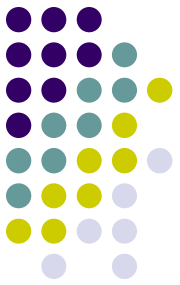
YES!



reconstruction interpretation

INITIAL interpretation

Children's behavior: Argument vs. Predicate contrast



Argument

Adult's INITIAL
= Child's ONLY



John knew **which** picture of himself [Bill saw ___]



surface interpretation
INITIAL interpretation

~~reconstruction interpretation~~
~~SECOND interpretation~~

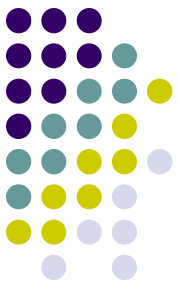
Predicate

John knew **how** proud of himself [Bill was ___]



reconstruction interpretation
INITIAL interpretation



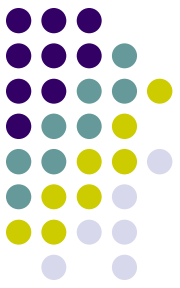


Summary so far

Adult's *initial* interpretation

= Child's *only* interpretation

- Child's divergence is due to a difference in the parser, not in grammar (Leddin & Lidz 2005)

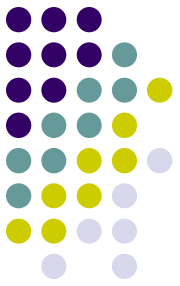


Summary so far

Adult's *initial* interpretation

= Child's *only* interpretation

- Child's divergence is due to a difference in the parser, not in grammar (Leddin & Lidz 2005)
- Is the hypothesized time-course plausible?



Experiment outline

Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

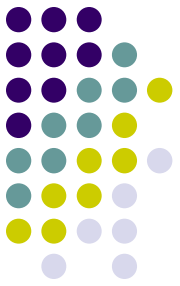
SECOND interpretation

Predicate

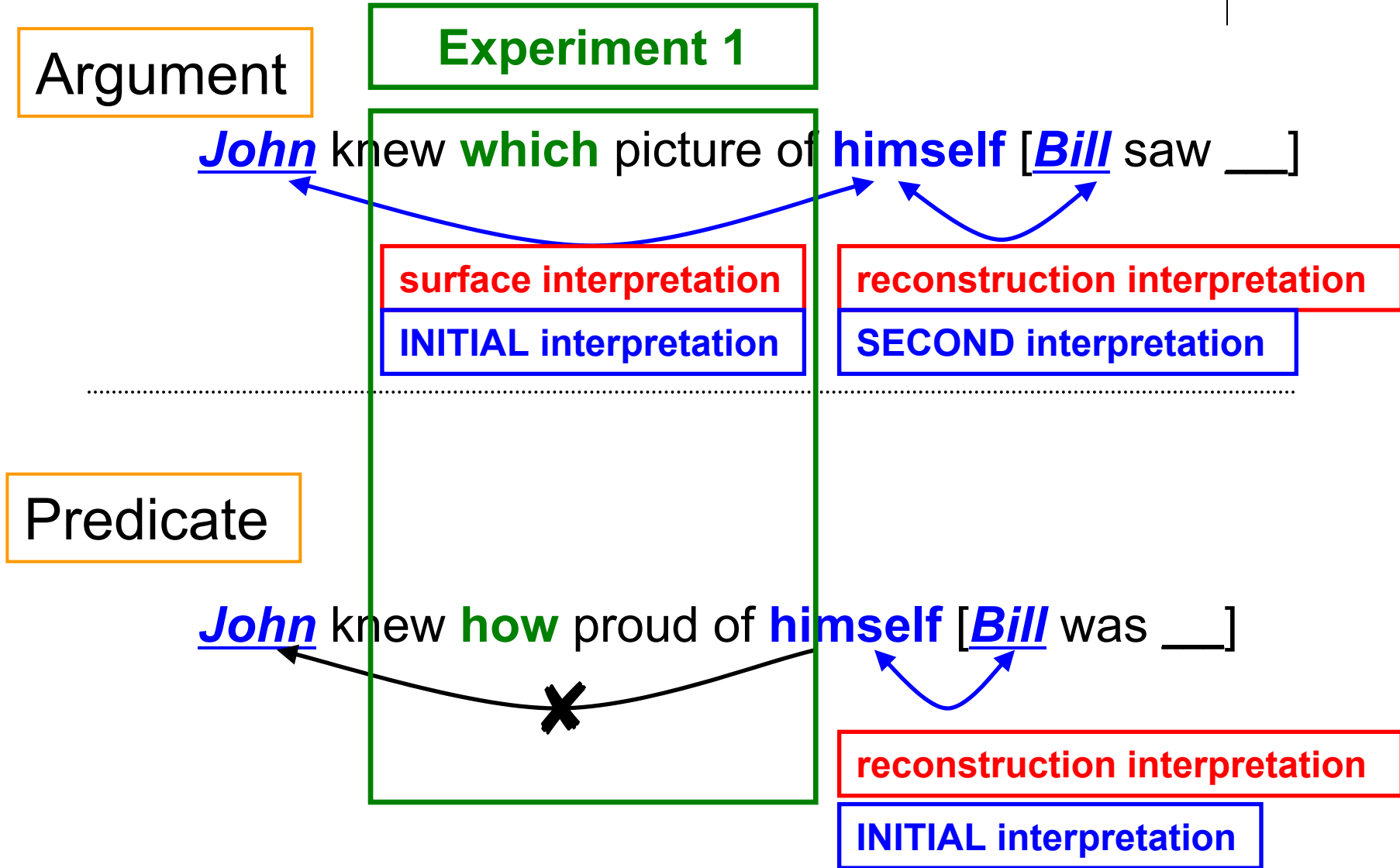
John knew **how** proud of himself [Bill was ___]

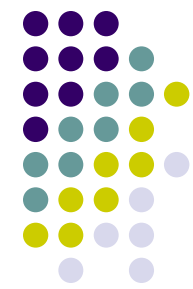
reconstruction interpretation

INITIAL interpretation

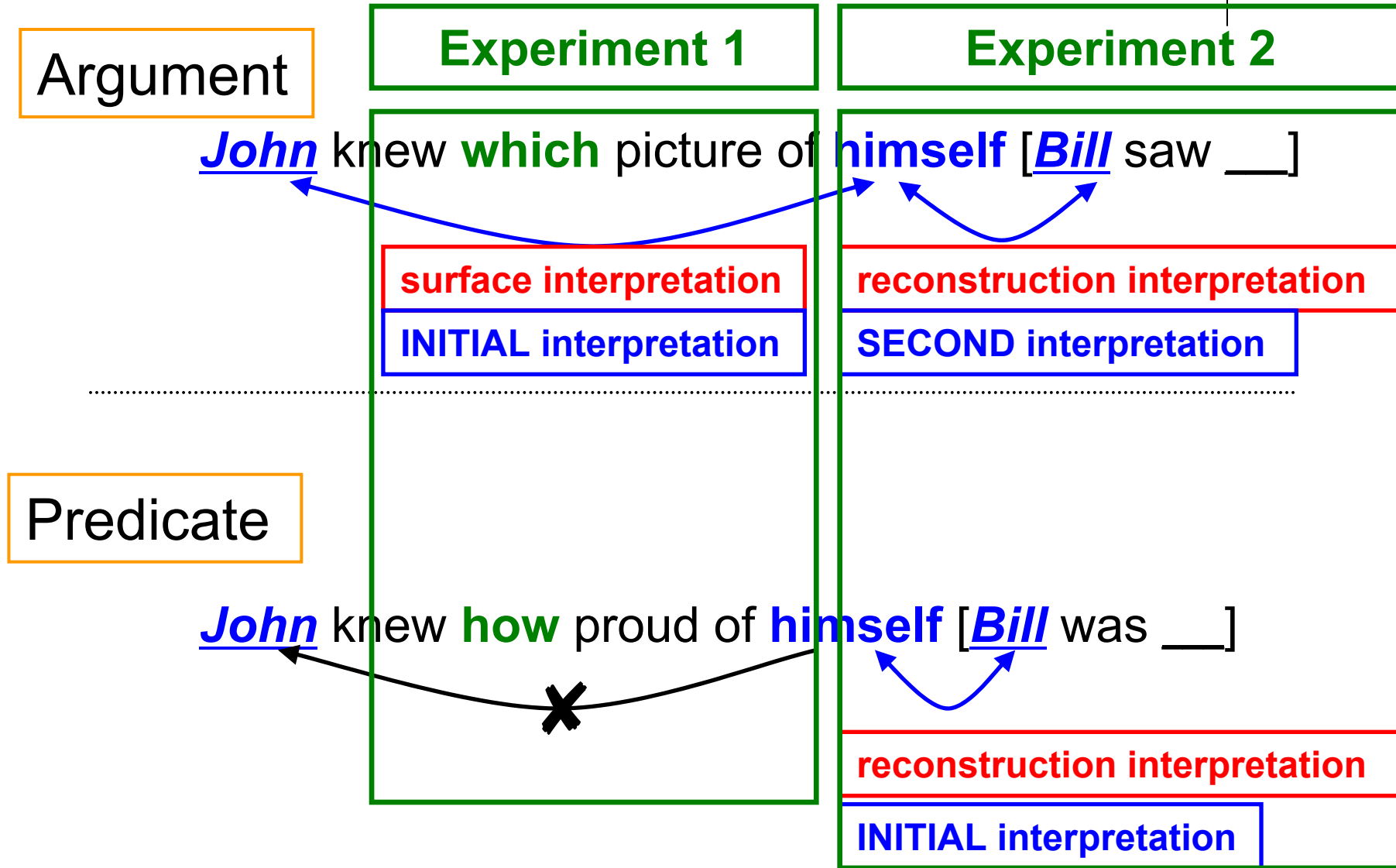


Experiment outline

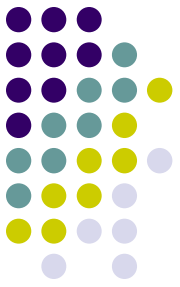




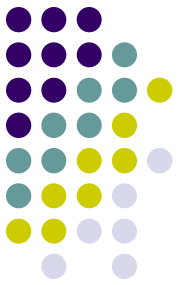
Experiment outline



Experiment 1a: Self-paced reading



- 4 conditions (Arg vs. Pred x Match vs. Mismatch)
- 24 targets (4 lists), 96 fillers
- 24 participants
- word-by-word, moving window



Experiment 1a: Design

Argument

Patrick knew **which** picture of **himself** ...

Rachel

surface interpretation

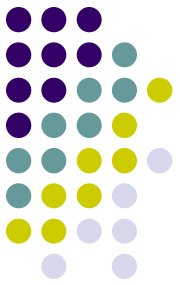
INITIAL interpretation

Predicate

Patrick knew **how** proud of **himself** ...

Rachel





Experiment 1a: Design

Argument

Patrick knew **which** picture of **himself** ...

Rachel

surface interpretation

INITIAL interpretation



Predicate

Patrick knew **how** proud of **himself** ...

Rachel





Experiment 1a: Design

Argument

Patrick knew **which** picture of **himself** ...

Rachel

surface interpretation

INITIAL interpretation



Predicate

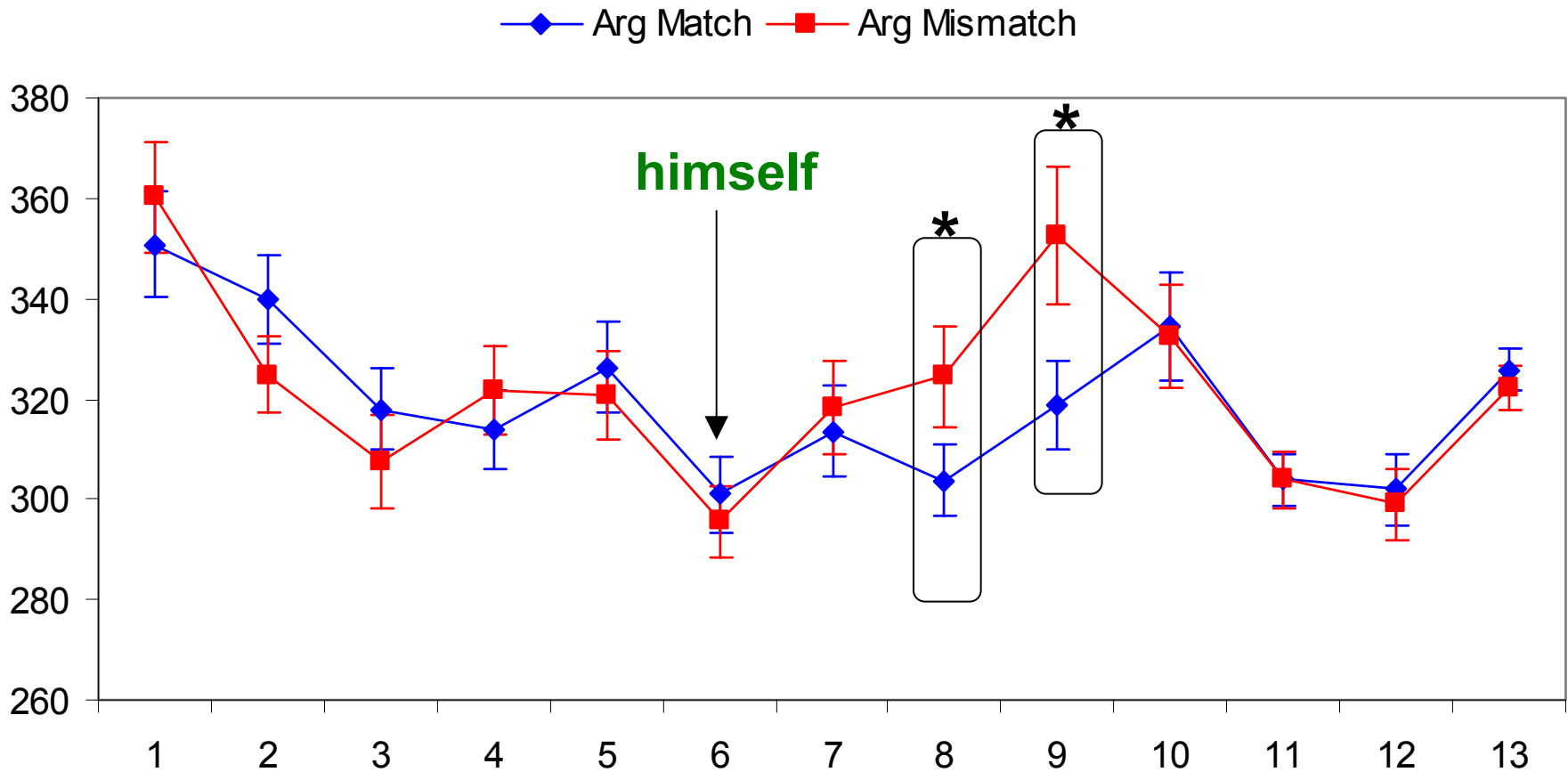
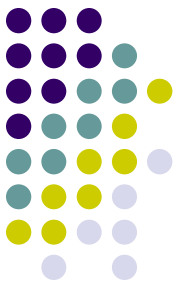
Patrick knew **how** proud of **himself** ...

Rachel

No GMME

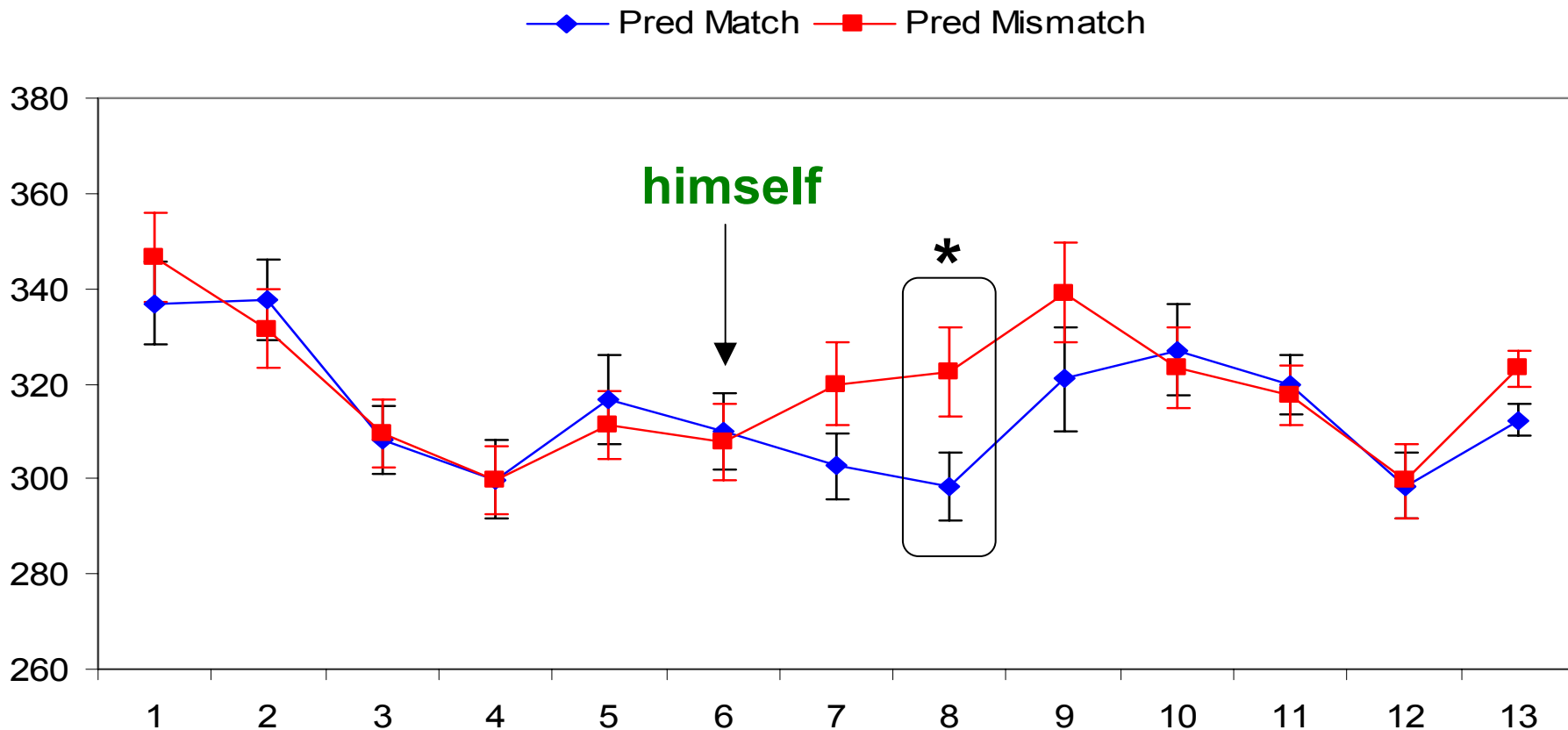
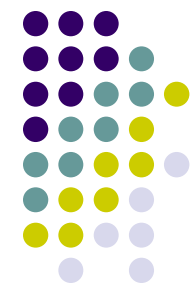


Experiment 1a: Argument condition

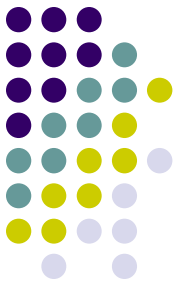


Patrick / Rachel knew which rumor about himself the popular highschool quarterback was likely to spread...

Experiment 1a: Predicate condition



Patrick / Rachel knew how ashamed of himself the popular highschool quarterback was likely to feel ...



Experiment 1a: Summary

Argument

Patrick knew **which** picture of **himself** ...

Rachel

surface interpretation

INITIAL interpretation



Predicate

Patrick knew **how** proud of **himself** ...

Rachel

No GMME





Experiment 1a: Summary

Argument

Patrick knew **which** picture of **himself** ...

Rachel

surface interpretation

INITIAL interpretation

GMM!

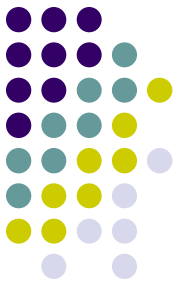
Confirmed!

Predicate

Patrick knew **how** proud of **himself** ...

Rachel

No GMME



Experiment 1a: Summary

Argument

Patrick knew **which** picture of **himself** ...

Rachel

surface interpretation

INITIAL interpretation

GMM!

Confirmed!

Predicate

Patrick knew **how** proud of **himself** ...

Rachel

No GMME

Not confirmed...

Immediate resolution in predicate condition?



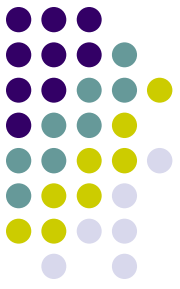
- Is the antecedent search not fully constrained by grammar?

Immediate resolution in predicate condition?



- Is the antecedent search not fully constrained by grammar?
- However, the surface interpretation is available if there is a pronoun in the embedded clause

Immediate resolution in predicate condition?



- Is the antecedent search not fully constrained by grammar?
- However, the surface interpretation is available if there is a pronoun in the embedded clause

John₁ forgot how proud of himself₁ he₁ was...

Immediate resolution in predicate condition?

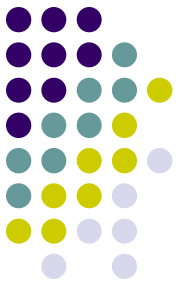


- Is the antecedent search not fully constrained by grammar?
- However, the surface interpretation is available if there is a pronoun in the embedded clause

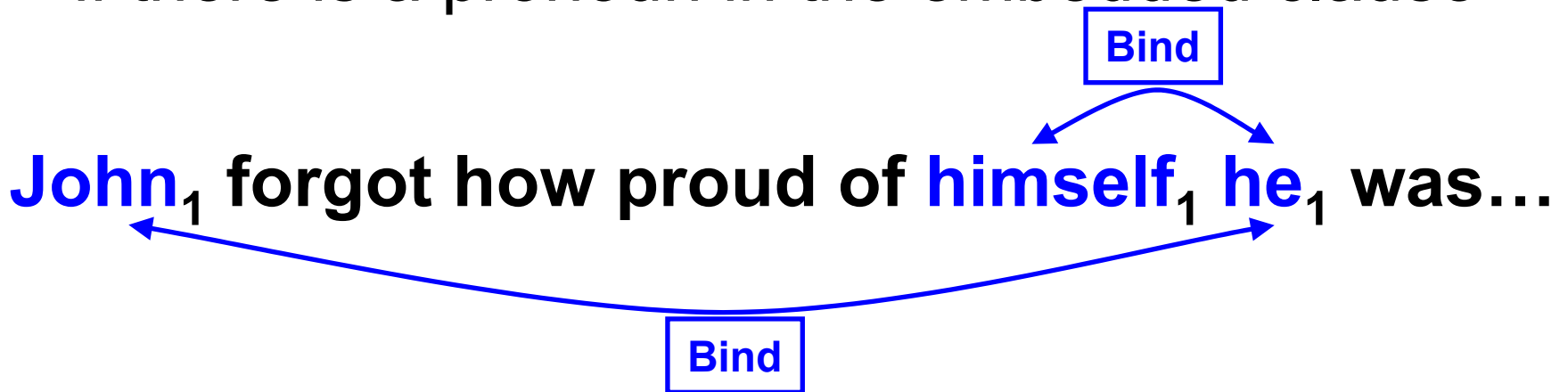
John₁ forgot how proud of himself₁ **he**₁ was...

A blue arrow points from the pronoun 'he' to the name 'John'. Below the arrow is a blue-bordered box containing the word 'Bind', indicating a binding relationship between the two.

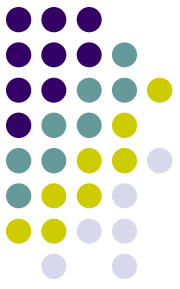
Immediate resolution in predicate condition?



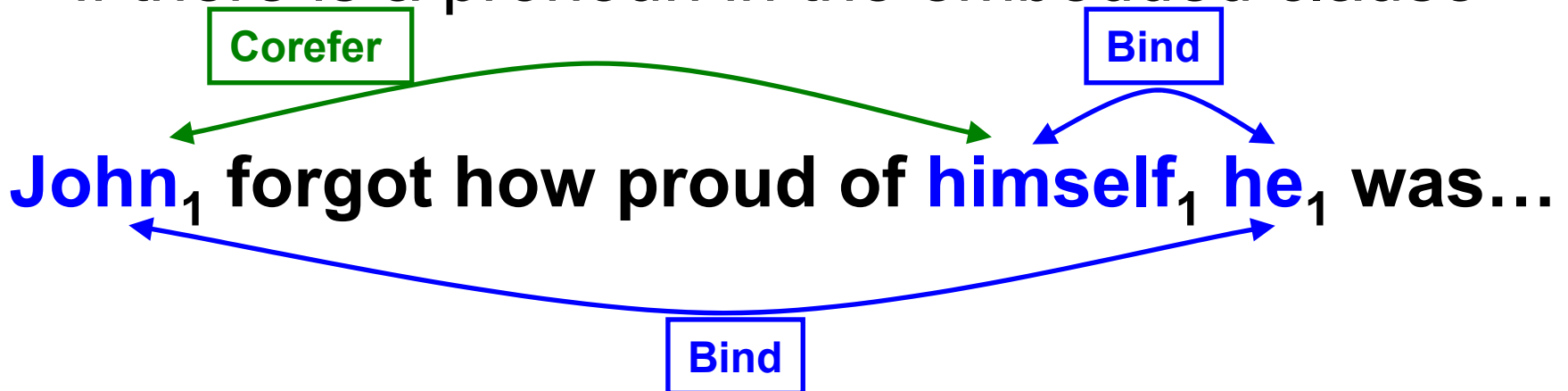
- Is the antecedent search not fully constrained by grammar?
- However, the surface interpretation is available if there is a pronoun in the embedded clause



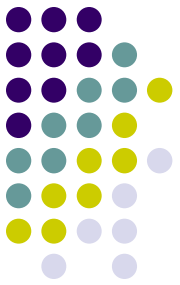
Immediate resolution in predicate condition?



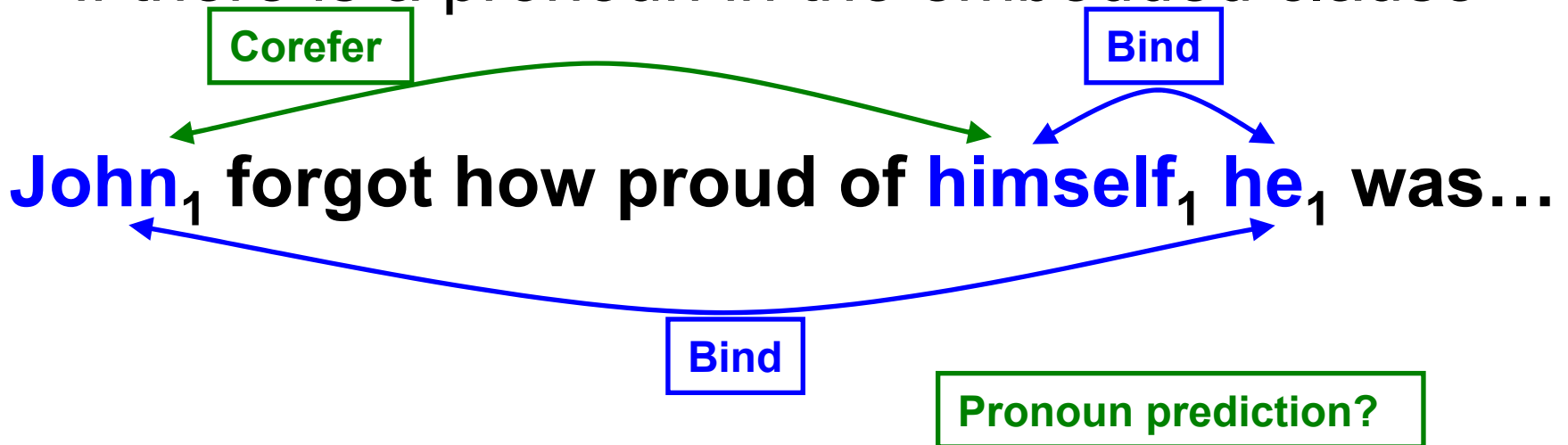
- Is the antecedent search not fully constrained by grammar?
- However, the surface interpretation is available if there is a pronoun in the embedded clause



Immediate resolution in predicate condition?

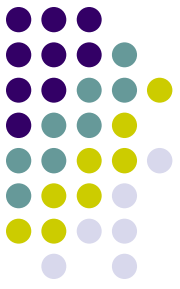


- Is the antecedent search not fully constrained by grammar?
- However, the surface interpretation is available if there is a pronoun in the embedded clause



Experiment 1b:

Sentence completion



- Tests if pronouns are predicted in predicate match condition
- Sentence completion results often correlate with predictive behavior in on-line comprehension
- N = 16

Experiment 1b:

Sentence completion



argument, **match**

Josh knew which picture of himself...

argument, **mismatch**

Jeniffer knew which picture of himself...

predicate, **match**

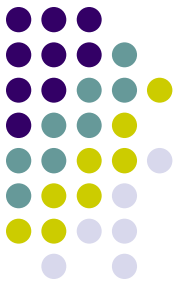
Josh knew how pleased with himself...

predicate, **mismatch**

Jeniffer knew how pleased with himself...

Experiment 1b:

Sentence completion



argument, **match**

Josh knew which picture of himself...

argument, **mismatch**

Jeniffer knew which picture of himself...

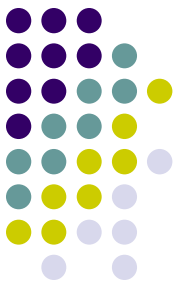
predicate, **match**

Josh knew how pleased with himself... he?

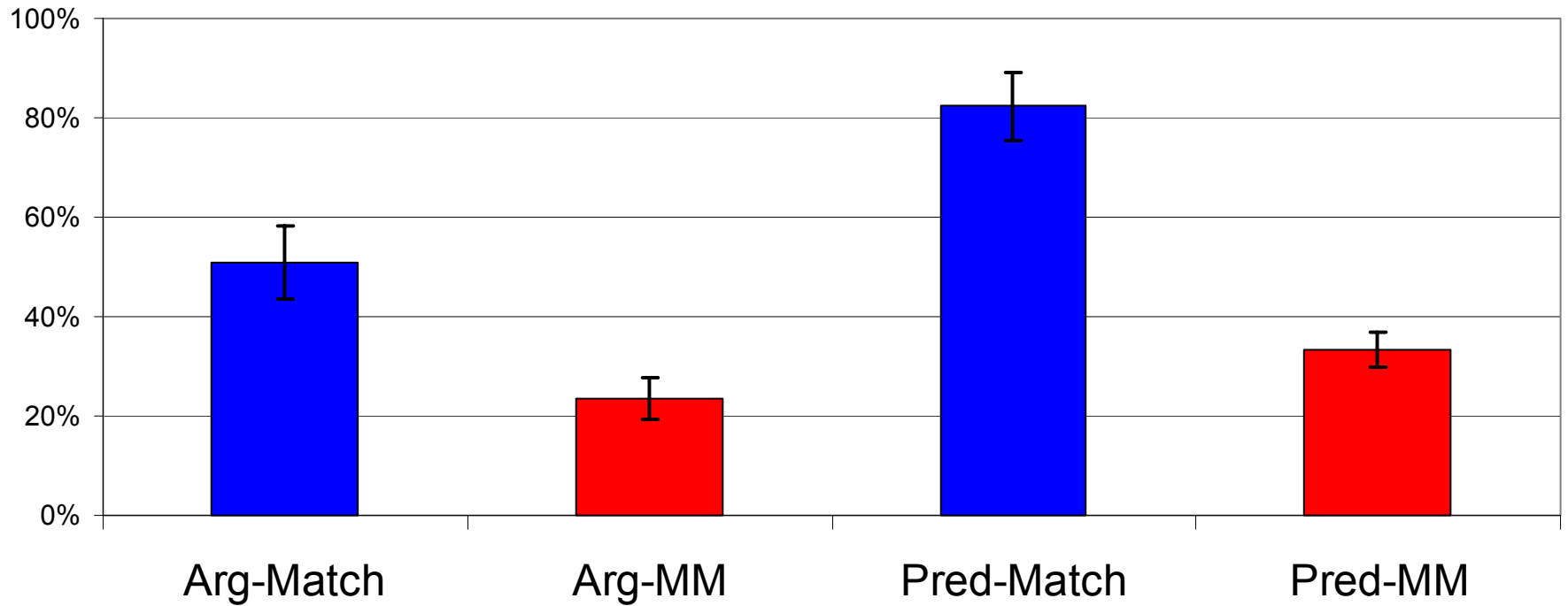
predicate, **mismatch**

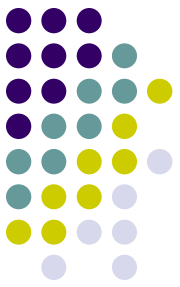
Jeniffer knew how pleased with himself...

Experiment 1b: Sentence completion



pronoun production





Experiment 1a & 1b: Summary

Argument

Patrick knew **which** picture of **himself** ...

Rachel

surface interpretation

INITIAL interpretation

GMM!

Confirmed!

Predicate

Patrick knew **how** proud of **himself** ...

Rachel

No GMME

Not confirmed...



Experiment 1a & 1b: Summary

Argument

Patrick knew **which** picture of **himself** ...

Rachel

surface interpretation

INITIAL interpretation

GMM!

Confirmed!

Predicate

Patrick knew **how** proud of **himself** ...

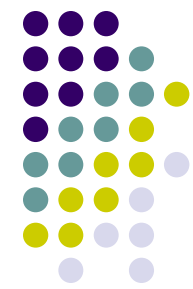
Rachel



No GMME

Not confirmed...

Pronoun prediction



Experiment 2

Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation
INITIAL interpretation

Experiment 2

reconstruction interpretation
SECOND interpretation

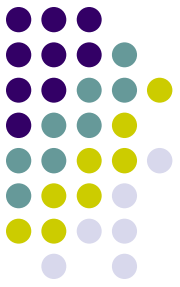
Predicate

John knew **how** proud of himself [Bill was ___]

reconstruction interpretation
INITIAL interpretation



Experiment 2: Self-paced reading



- 4 conditions (Arg vs. Pred x Match vs. Mismatch)
- 24 targets (4 lists), 96 fillers
- 44 participants
- word-by-word, moving window



Experiment 2 design

Argument

Patrick
Rachel knew **which** picture of **himself** **herself** [... alcoholic ...]

surface interpretation

INITIAL interpretation

reconstruction interpretation

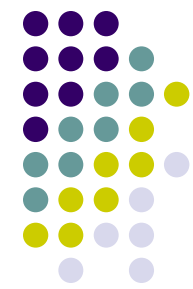
SECOND interpretation

Predicate

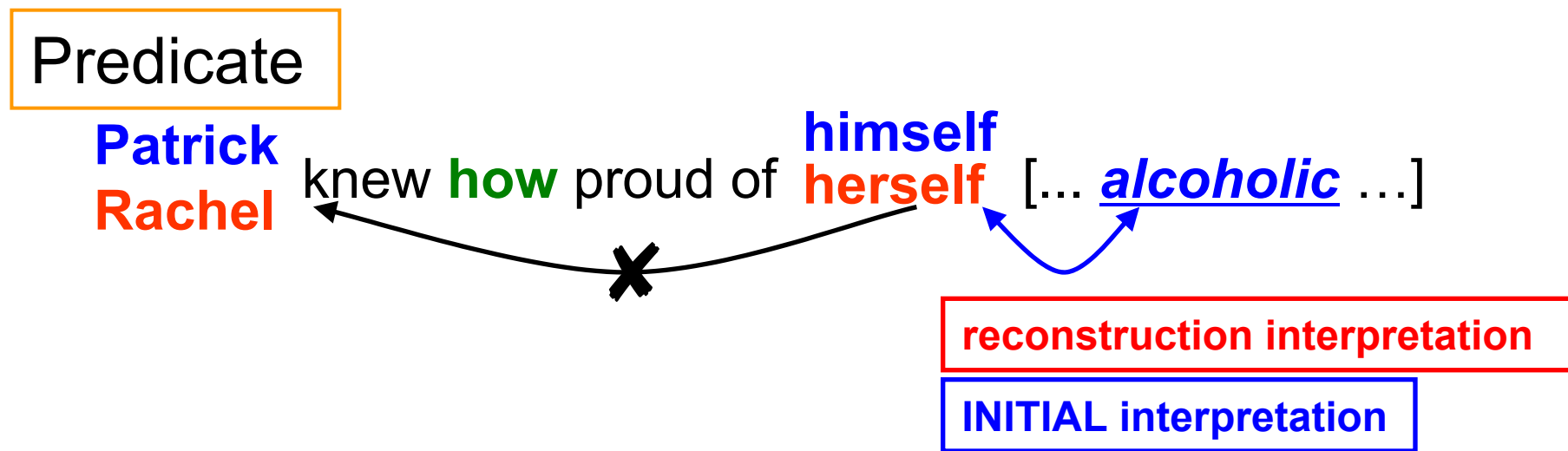
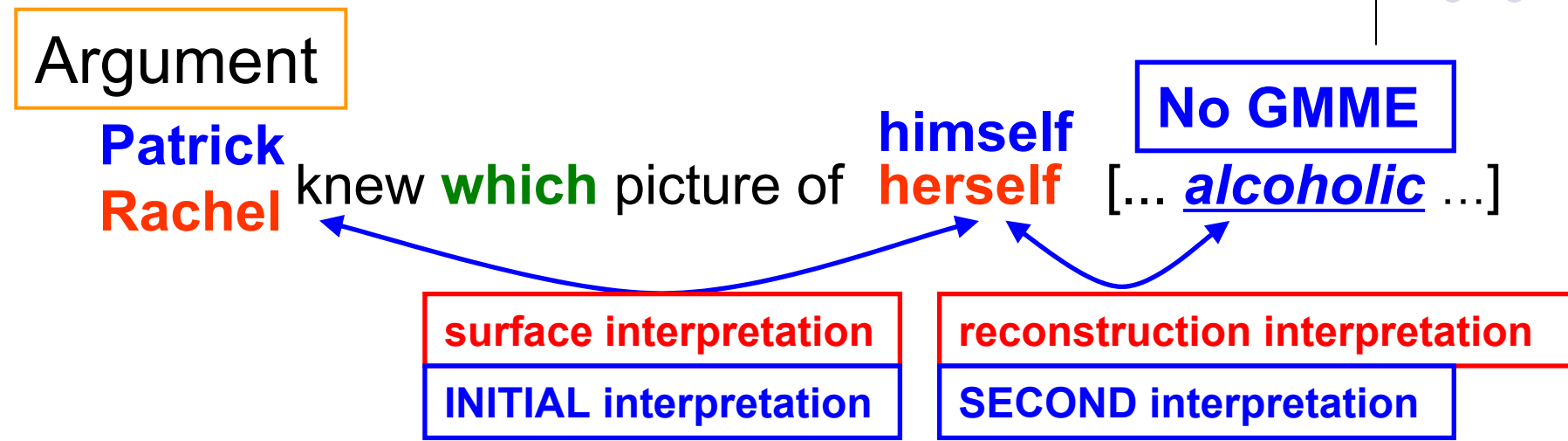
Patrick
Rachel knew **how** proud of **himself** **herself** [... alcoholic ...]

reconstruction interpretation

INITIAL interpretation

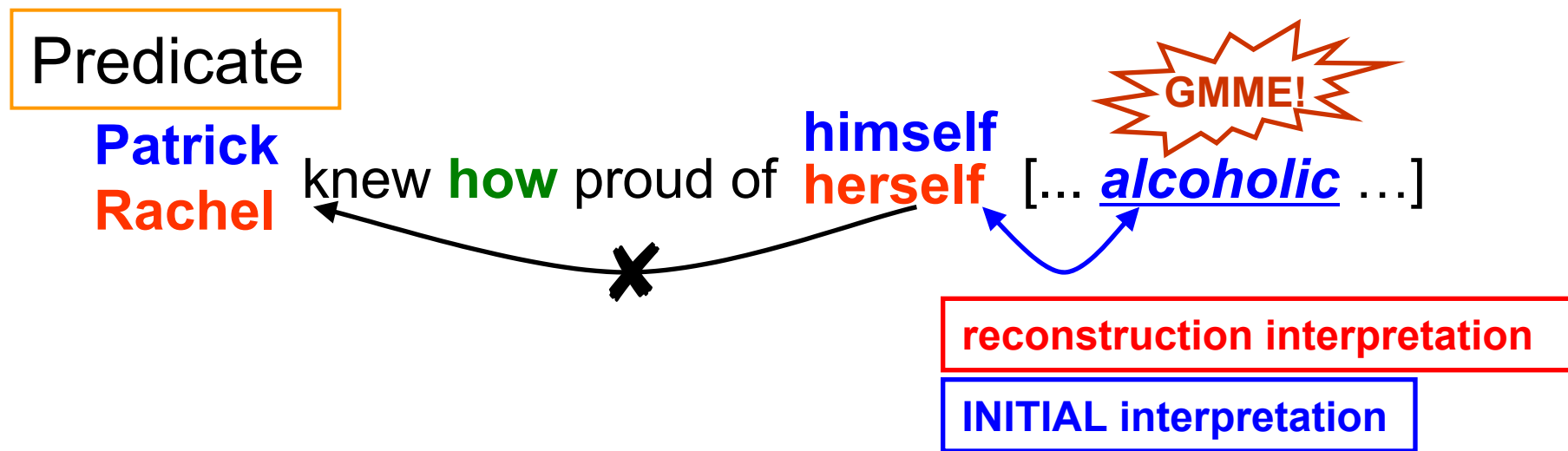
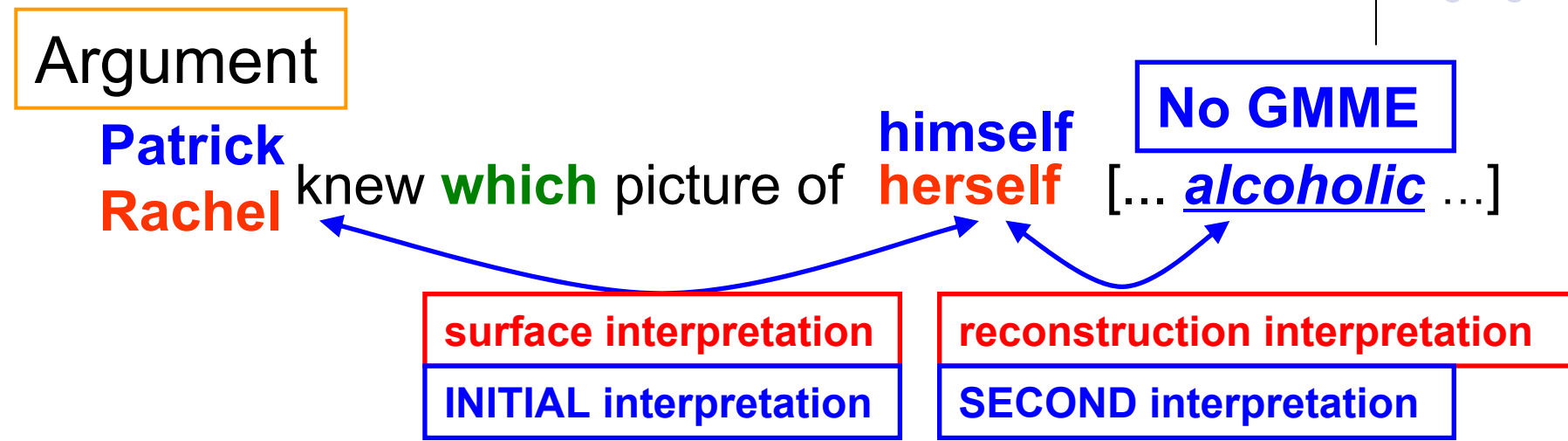


Experiment 2 design

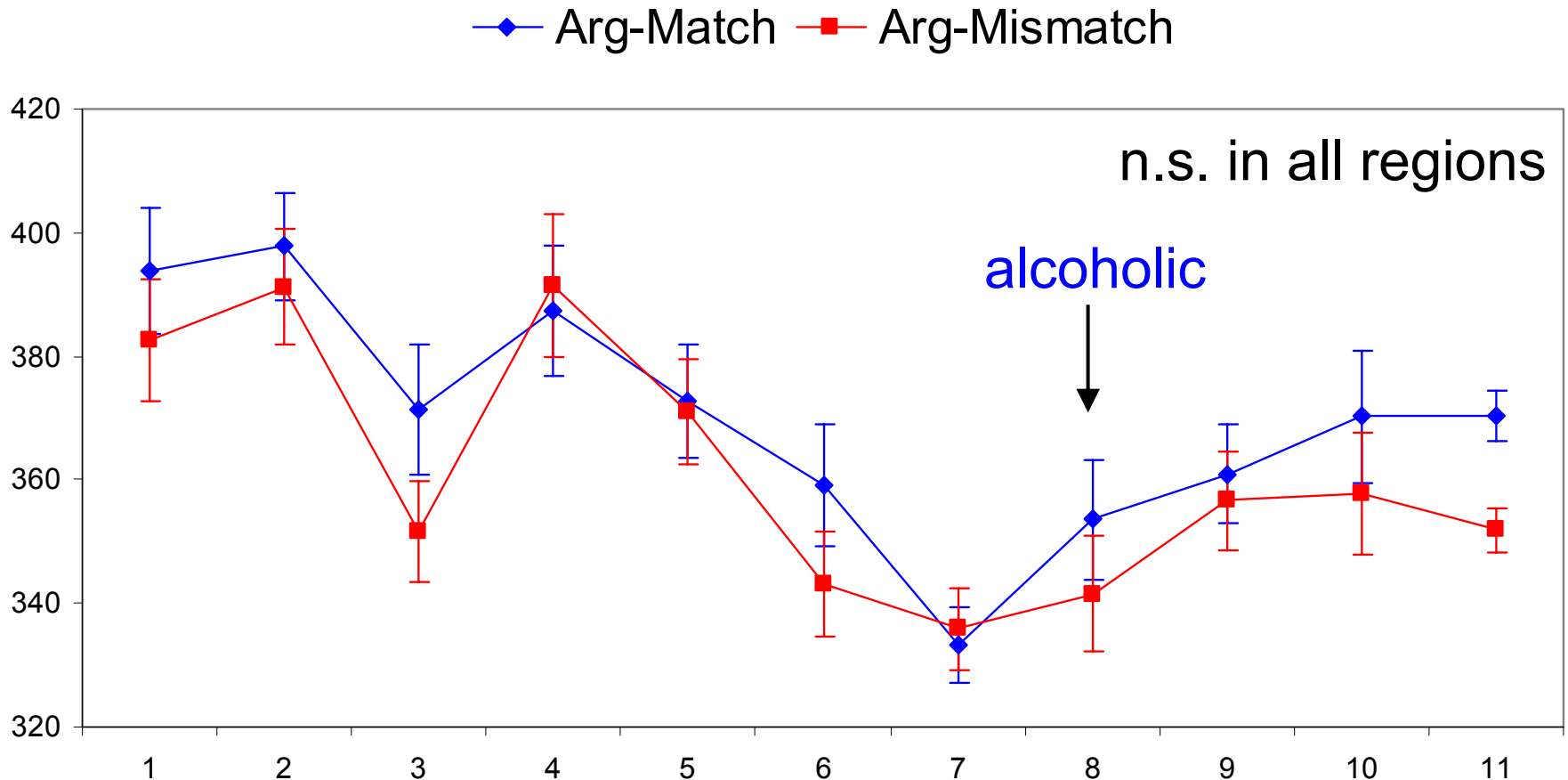




Experiment 2 design



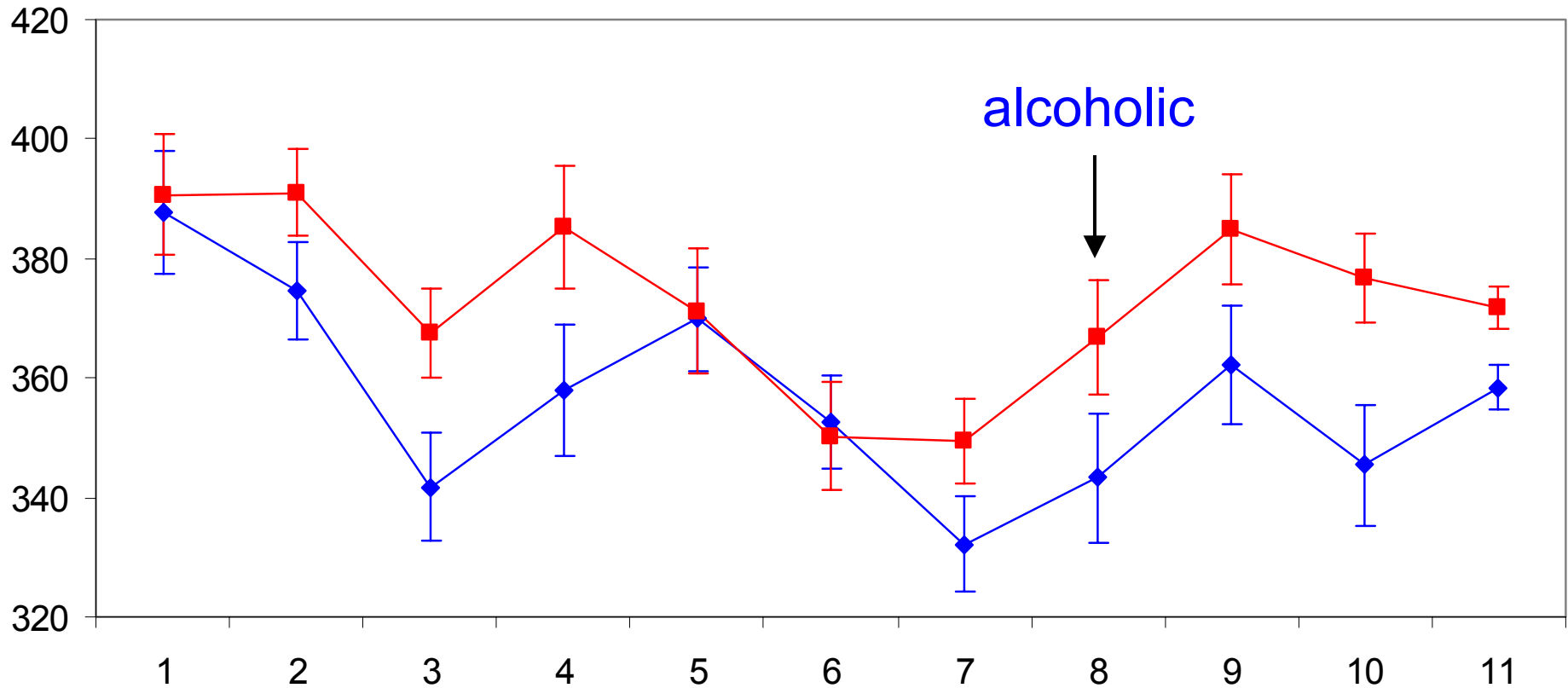
Exp 2 results: argument conditions



Patrick / Rachel found out which story about himself / herself
the alcoholic had spread ...

Exp 2 results: predicate conditions

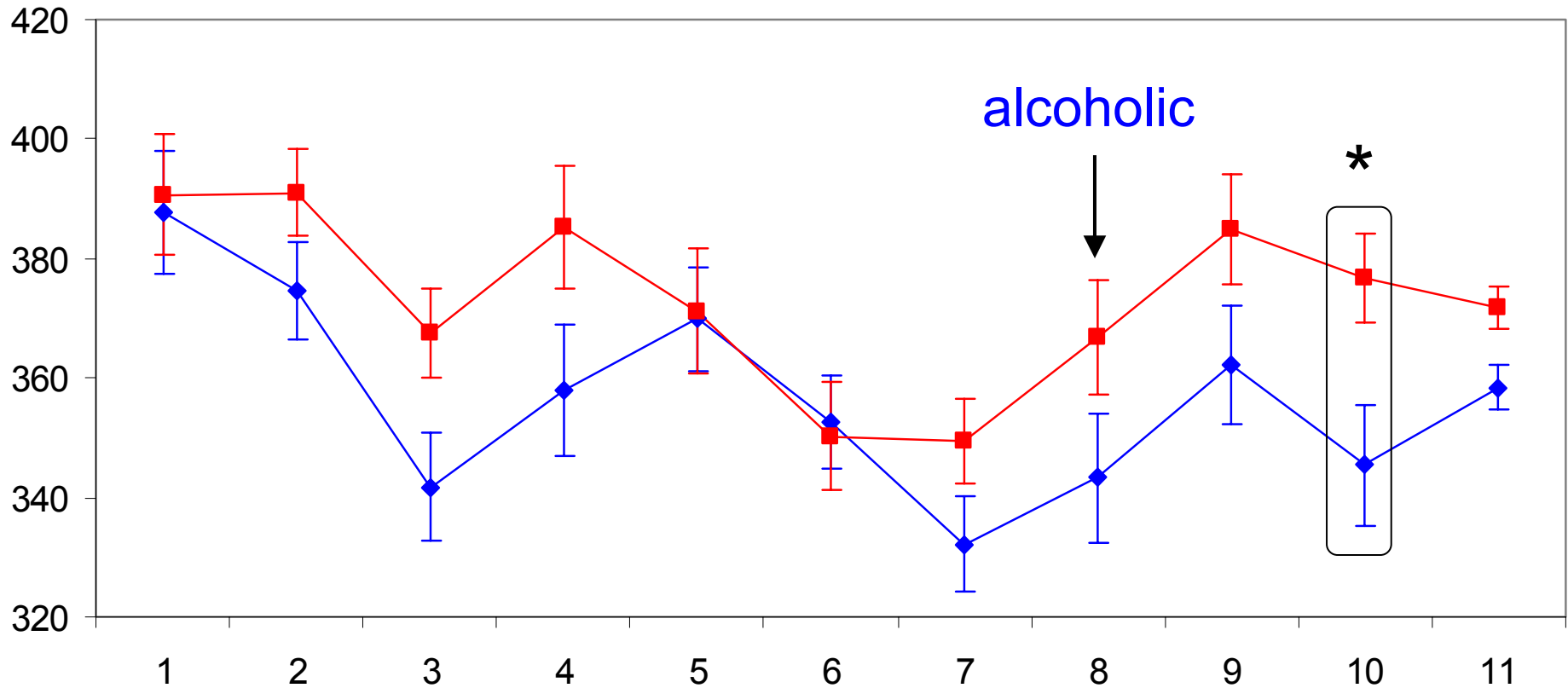
—◆— Pred-Match —■— Pred-Mismatch



Patrick / Rachel found out which story about himself / herself the alcoholic had spread ...

Predicate condition results: Linear Mixed-Effects Model

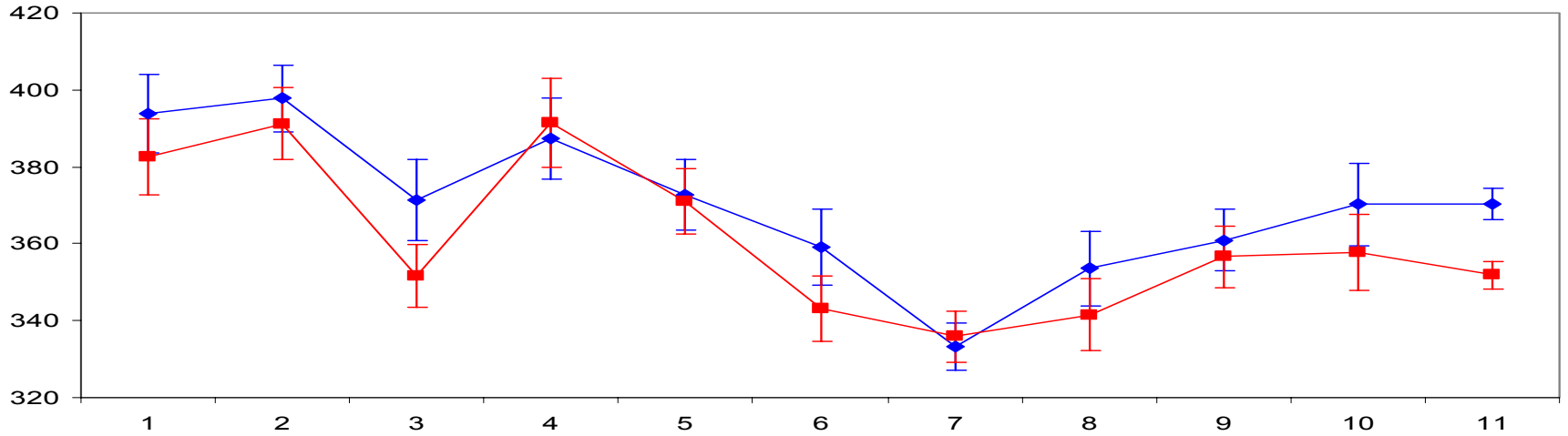
◆ Pred-Match ■ Pred-Mismatch



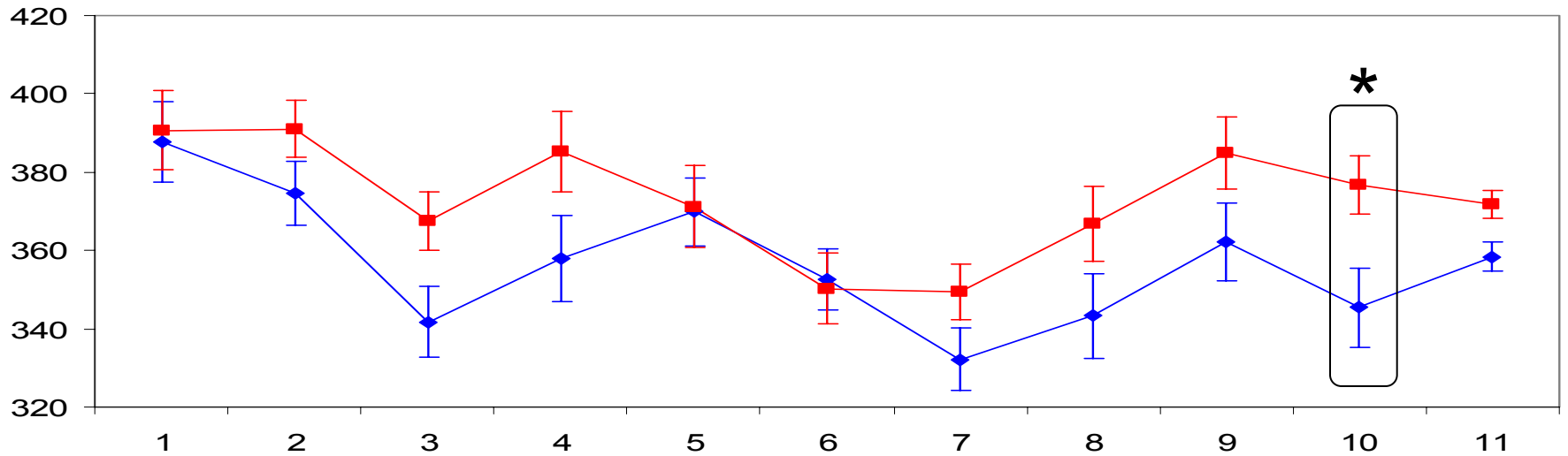
Factor out predicted amount of noise (e.g., spill-over effect)
based on non-experimental manipulation

Exp 2 results: Arg vs Pred

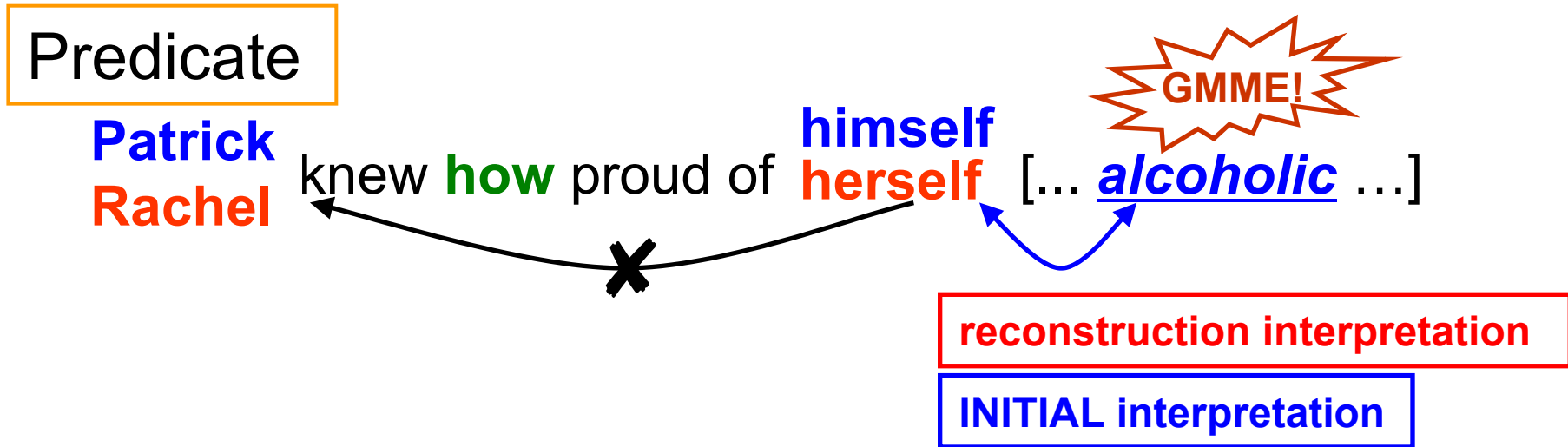
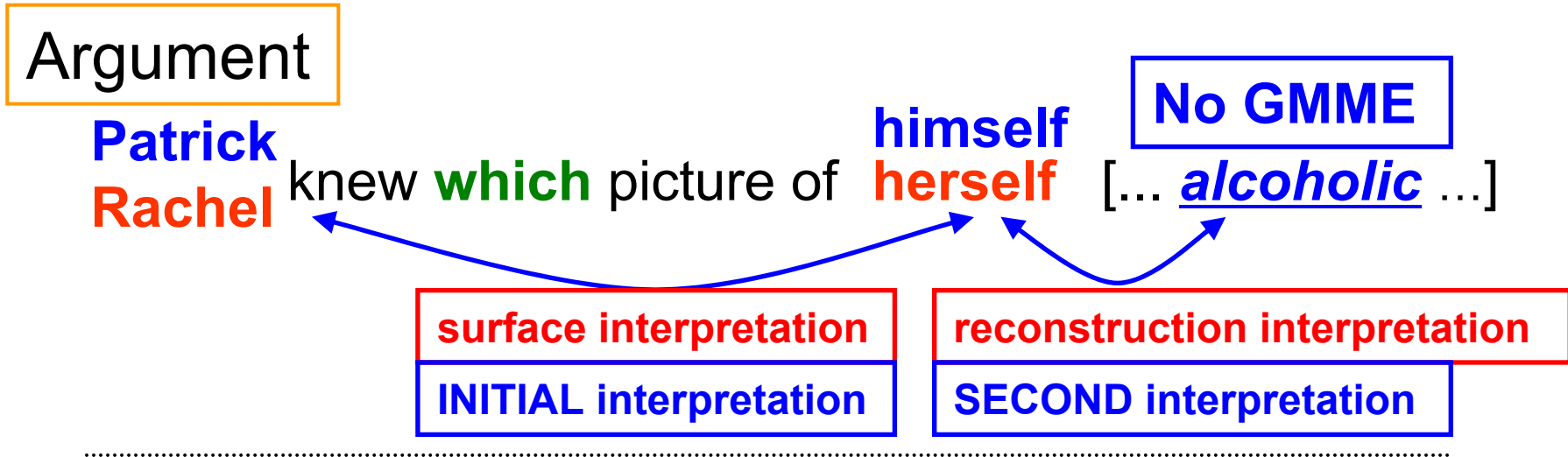
Arg-Match Arg-Mismatch



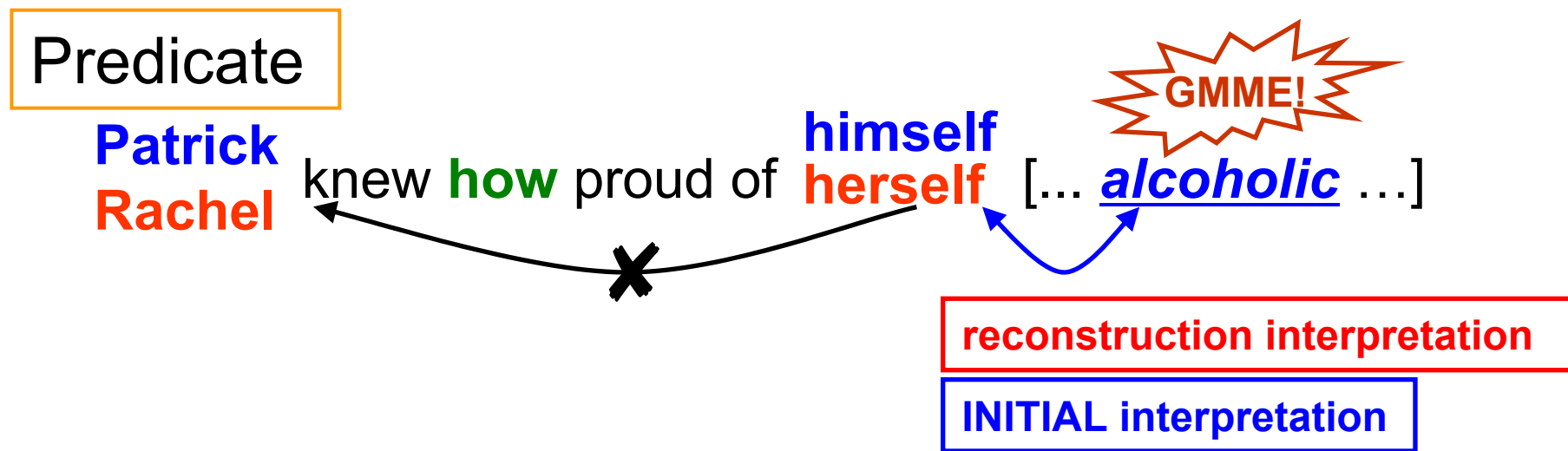
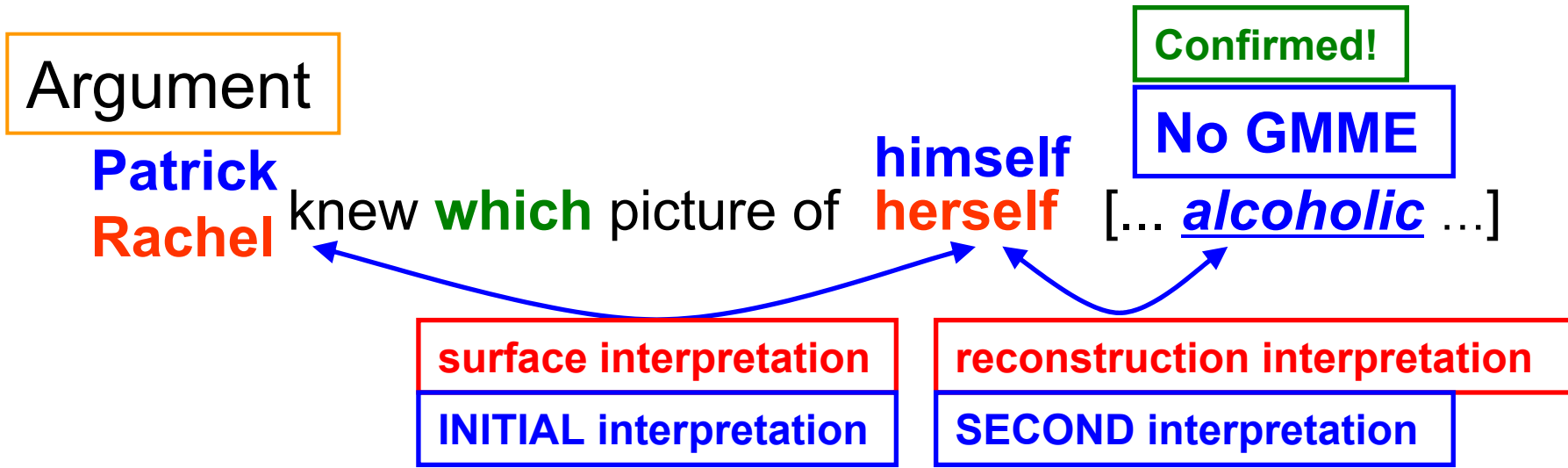
Pred-Match Pred-Mismatch



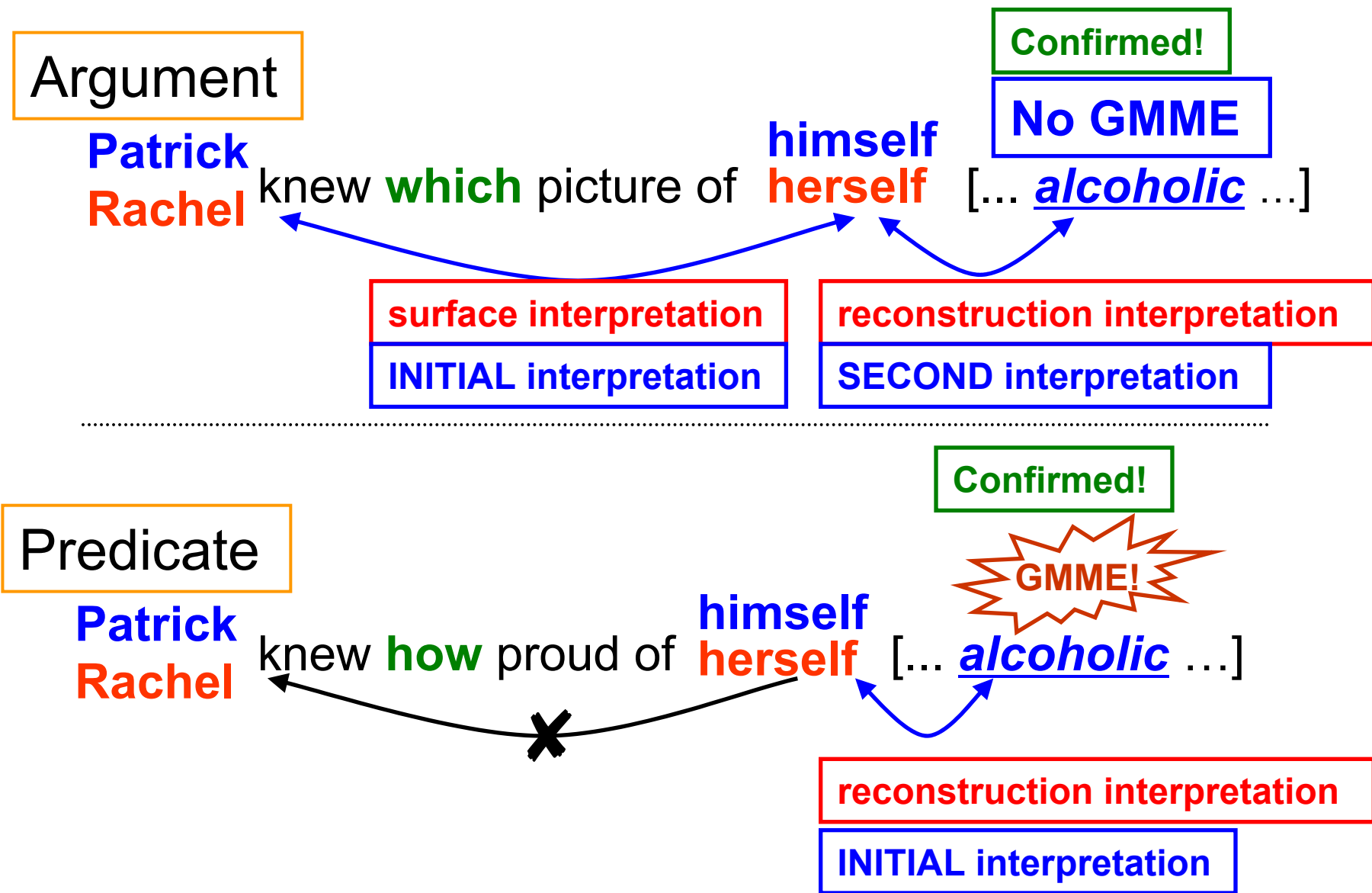
Experiment 2 summary



Experiment 2 summary



Experiment 2 summary



Discussion: Argument fronting

Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

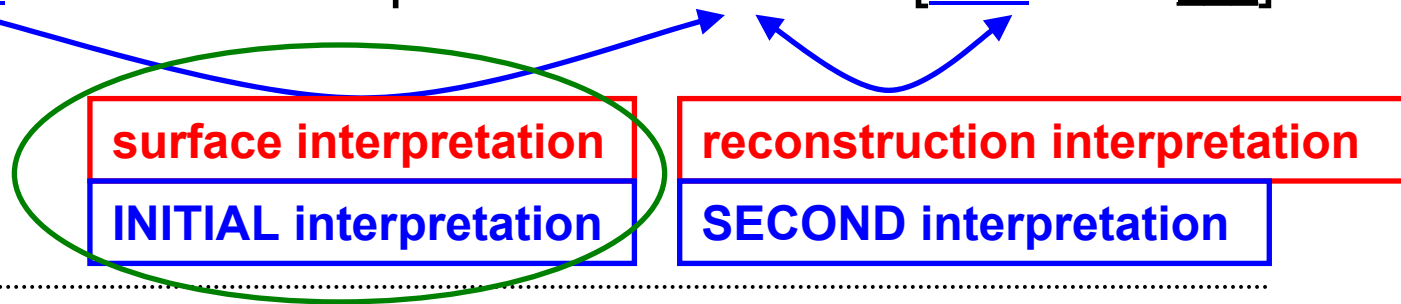
reconstruction interpretation

INITIAL interpretation

Discussion: Argument fronting

Argument

John knew **which** picture of himself [Bill saw ___]



Predicate

John knew **how** proud of himself [Bill was ___]



Discussion: Argument fronting

Argument

John knew **which** picture of himself [Bill saw ___]

surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

reconstruction interpretation

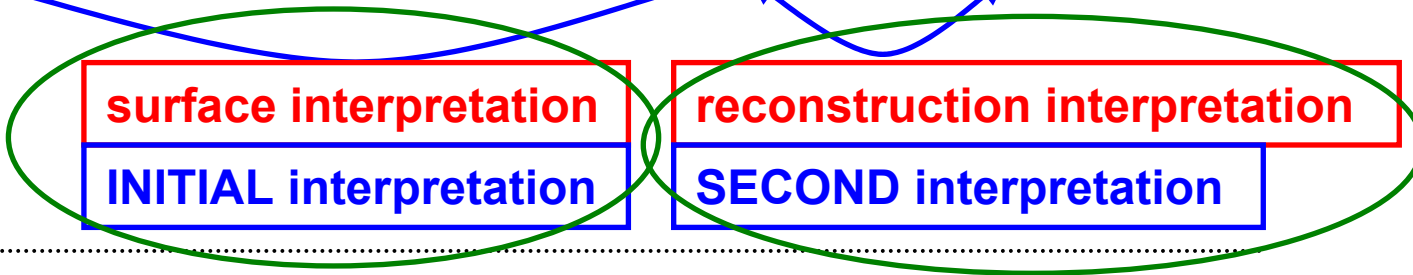
INITIAL interpretation

Discussion: Argument fronting



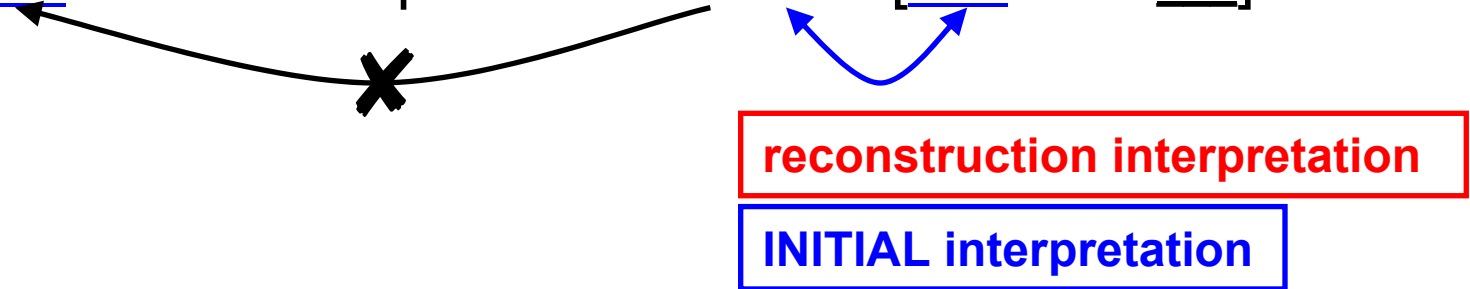
Argument

John knew **which** picture of himself [Bill saw ___]



Predicate

John knew **how** proud of himself [Bill was ___]



Discussion: Predicate fronting



Argument

John knew **which** picture of himself [Bill saw ___]



surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]

reconstruction interpretation

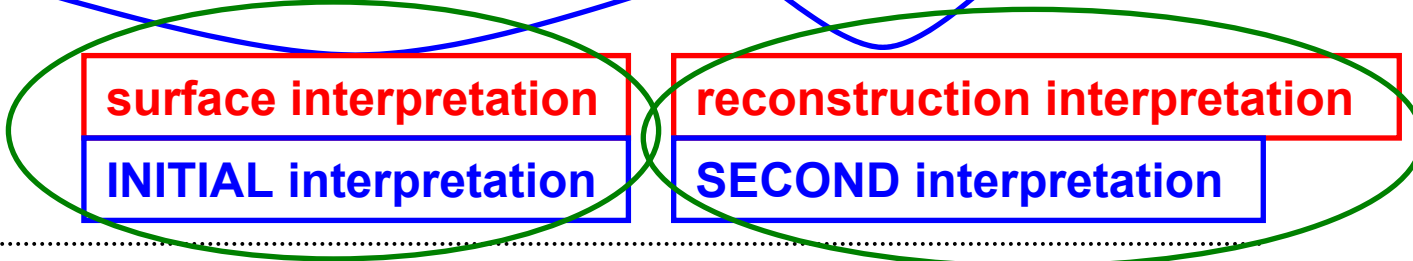
INITIAL interpretation

Discussion: Predicate fronting



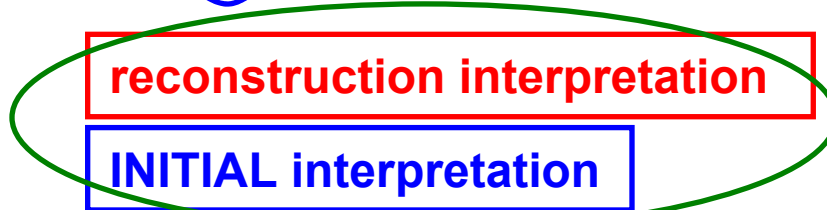
Argument

John knew **which** picture of himself [Bill saw ___]



Predicate

John knew **how** proud of himself [Bill was ___]

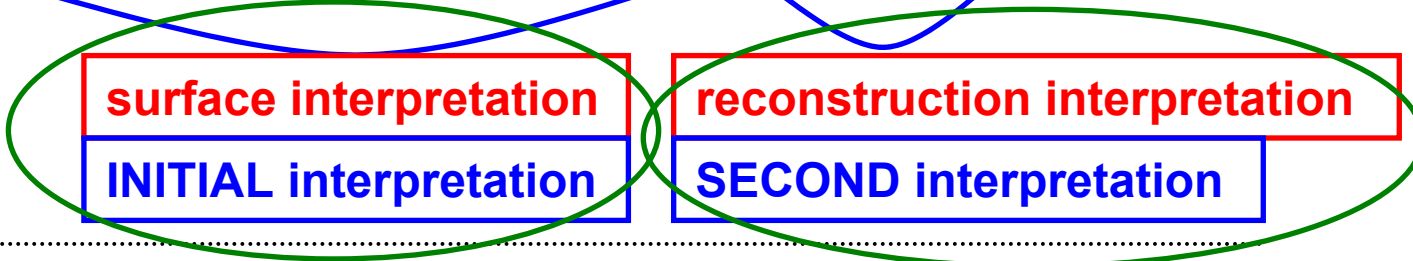


Discussion: Predicate fronting



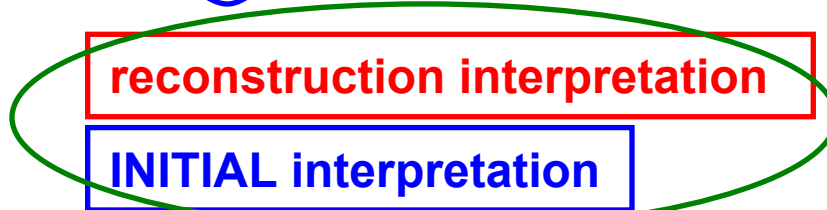
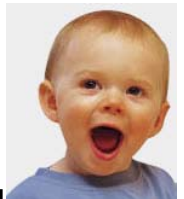
Argument

John knew **which** picture of himself [Bill saw ___]



Predicate

John knew **how** proud of himself [Bill was ___]



X

Discussion: Predicate fronting

Argument



John knew **which** picture of himself [Bill saw ___]



surface interpretation

INITIAL interpretation

reconstruction interpretation

SECOND interpretation

Predicate

John knew **how** proud of himself [Bill was ___]



Pronoun prediction

reconstruction interpretation

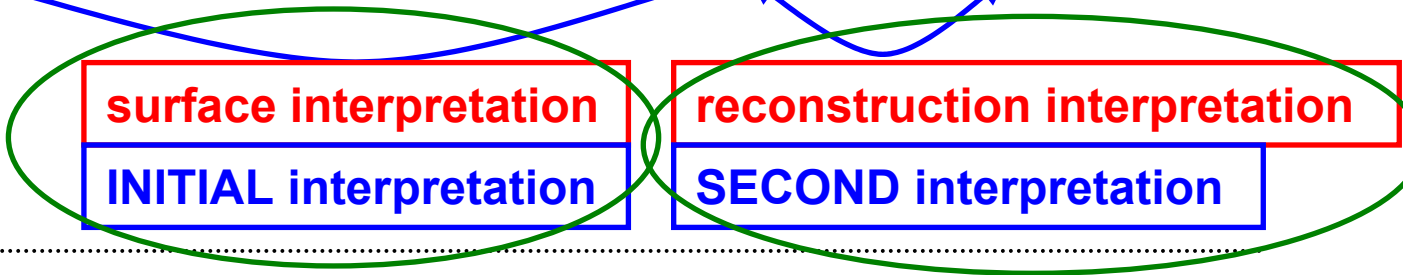
INITIAL interpretation

Discussion: Predicate fronting



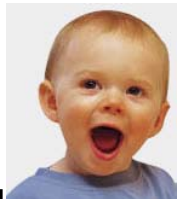
Argument

John knew **which** picture of himself [Bill saw ___]

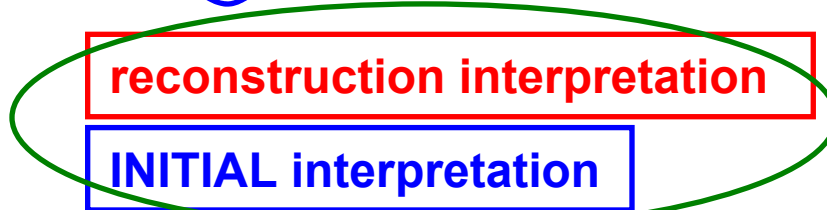


Predicate

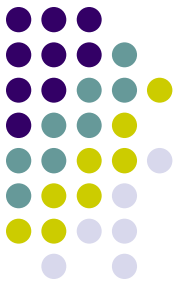
John knew **how** proud of himself [Bill was ___]



Pronoun prediction



Thank you



Anastasia Conroy

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Norbert Hornstein

Atakan Ince

Ellen Lau

Lisa Pearl

Barbara Schulz

Clare Stroud

Matt Wagers

Masaya Yoshida

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