Making and Correcting Errors during Sentence Comprehension:

Eye Movements in the Analysis of Structurally Ambiguous Sentences

PART 1

Reading through the Decades:

Influential Papers in Psycholinguistics – Seminar

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Frazier & Rayner (1982)

12/01/2016

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About **Frazier & Rayner (1982)**

– Introduction and Background

Question

- **How** does human language **processing** lead to **comprehension**?

Question

- **How** do humans **understand sentences**?

Question

- **How** do humans **deal with ambiguities**?

Question

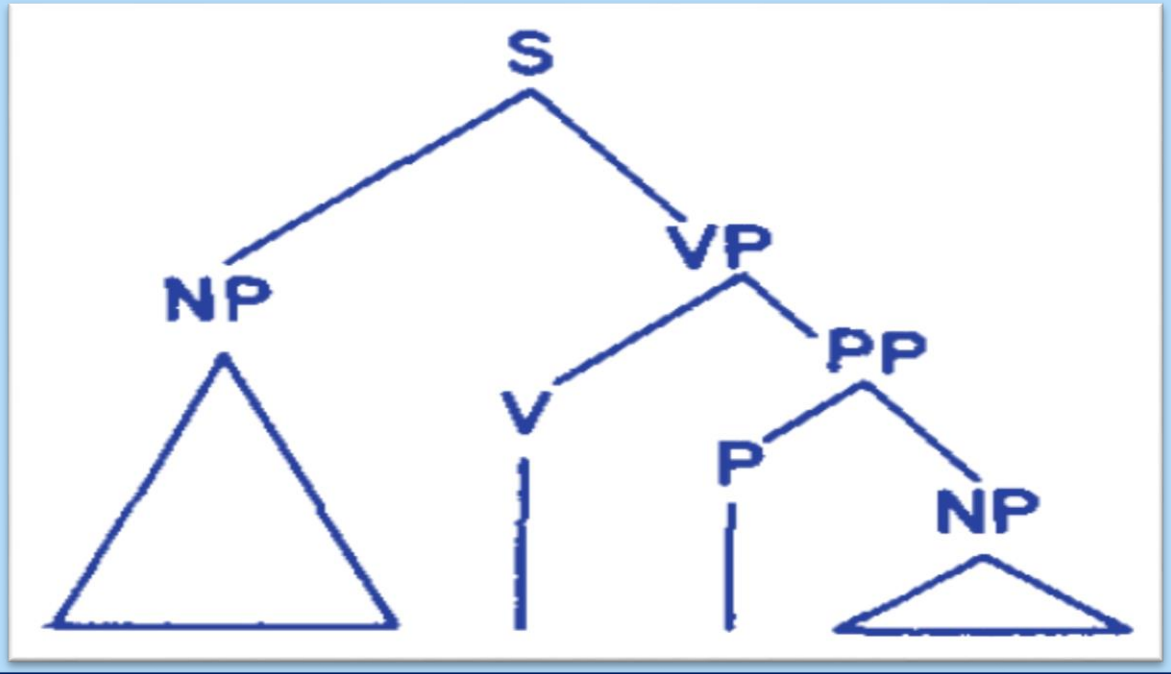
- **How** do humans **recover from mistakes**?

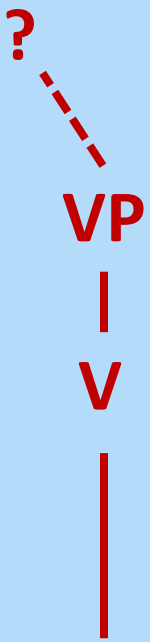
How did
Frazier & Rayner (1982)
seek to **answer**?

Possible Answer

- **Garden-Path Theory** of Sentence Comprehension

A Garden-Path Sentence





The horse raced past the barn fell

Garden-Path Theory

- **Initial, single analysis/interpretation**

- then, **more than one** possibility

Why ‘garden-path’?

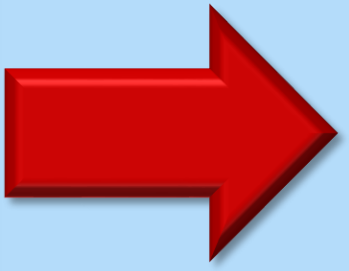
- “to **lead** someone **down the garden-path**”

- to mislead, deceive…

- **How** do humans **understand sentences**?

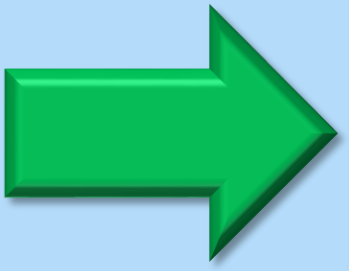
Garden-Path: Main Feature

- **G-P Theory**: analyses on a one-by-one basis



➢ 1st attempt

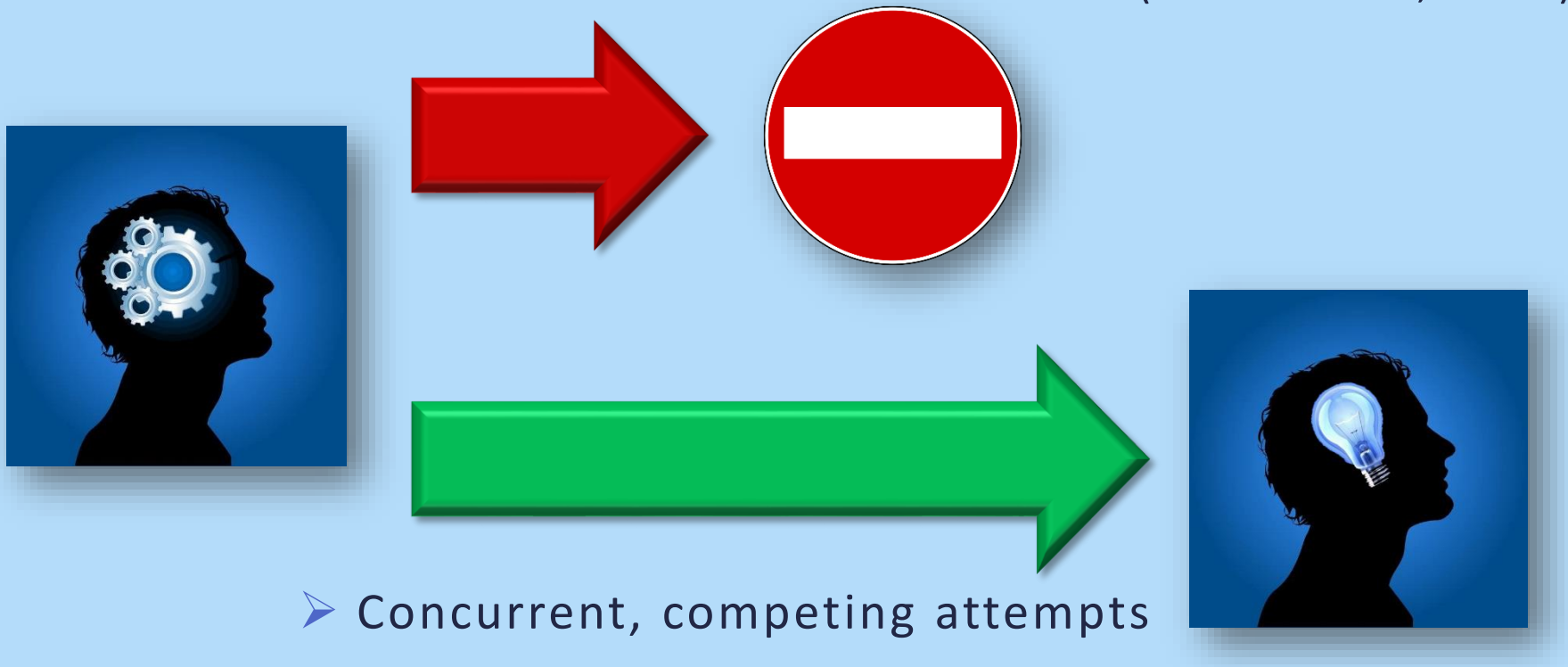
- **Serial** processing



➢ 2nd attempt

Garden-Path: One Contrasting View

- **Parallel Processing Hp**.: multiple, simultaneous analyses (Fodor et al., 1974)



  - Concurrent, competing attempts

- **Parallel** processing

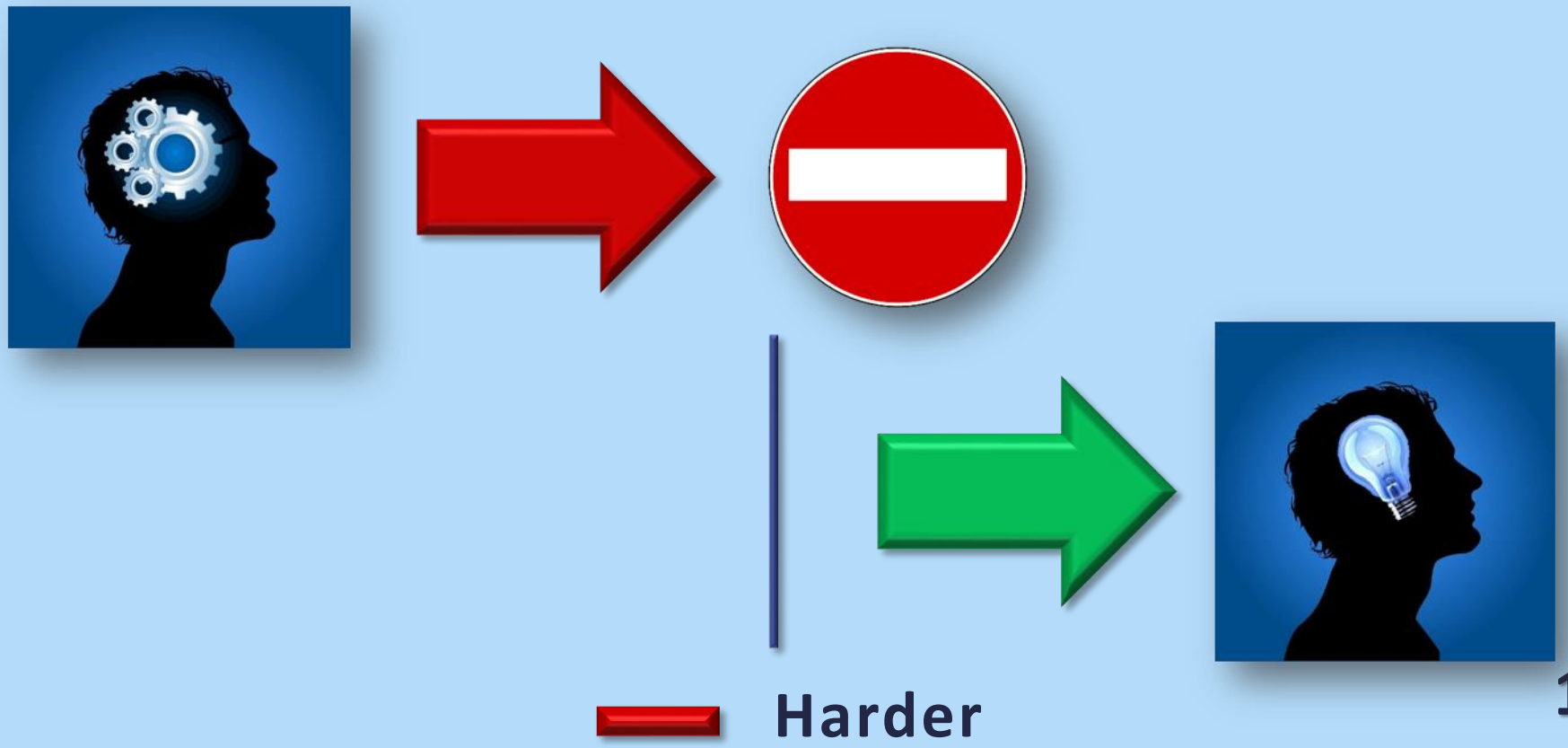
Garden-Path: Processing Difficulty [1]

- Depending on **in-/compatibility** between (initial) **interpretation** and **disambiguating material**:

Easier

Garden-Path: Processing Difficulty [2]

- Depending on **in-/compatibility** between (initial) **interpretation** and **disambiguating material**:



Garden-Path: Processing Difficulty [3]

- **Which** one is harder/easier?

a) Since Jay always jogs a mile this seems like a short distance to him

Easier

b) Since Jay always jogs a mile seems like a short distance to him

Harder

- **How** do humans **deal with ambiguities**?

Global vs. Local Ambiguities

- **Which** one is globally/locally ambiguous?

a) Someone shot the servant of the actress who was on the balcony

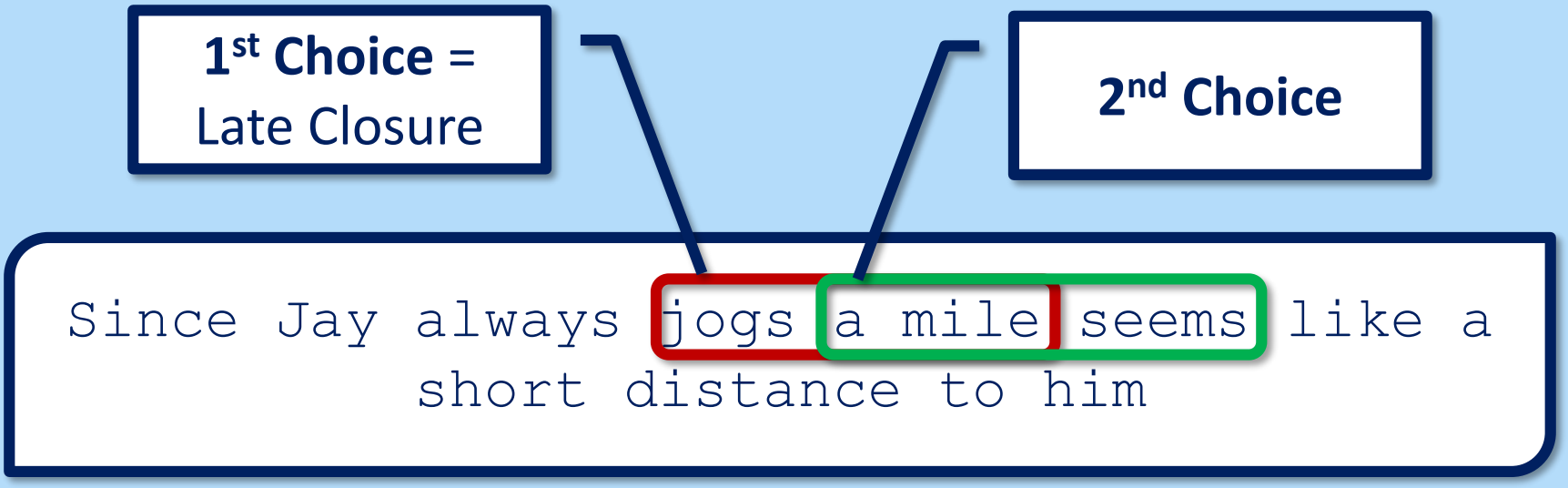
➢ **Globally** ambiguous

b) Wherever Alice walks her sheep dog will follow

➢ **Locally** ambiguous

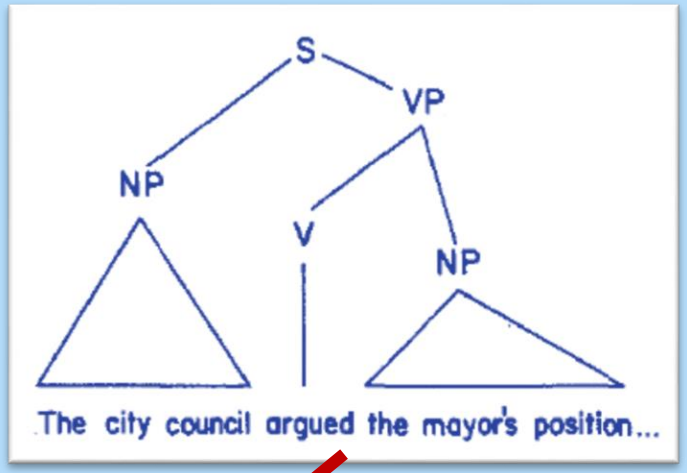
Garden-Path: Parsing Strategies [1]

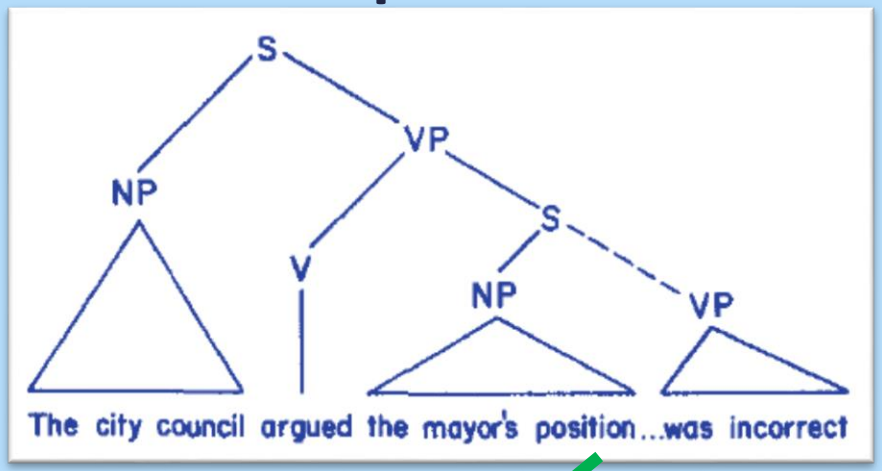
- **Late Closure**: attachment of incoming lexical material into the **last analysed item**



Garden-Path: Parsing Strategies [2]

- **Minimal Attachment**: attachment of incoming lexical material using the **fewest phrasal nodes**.



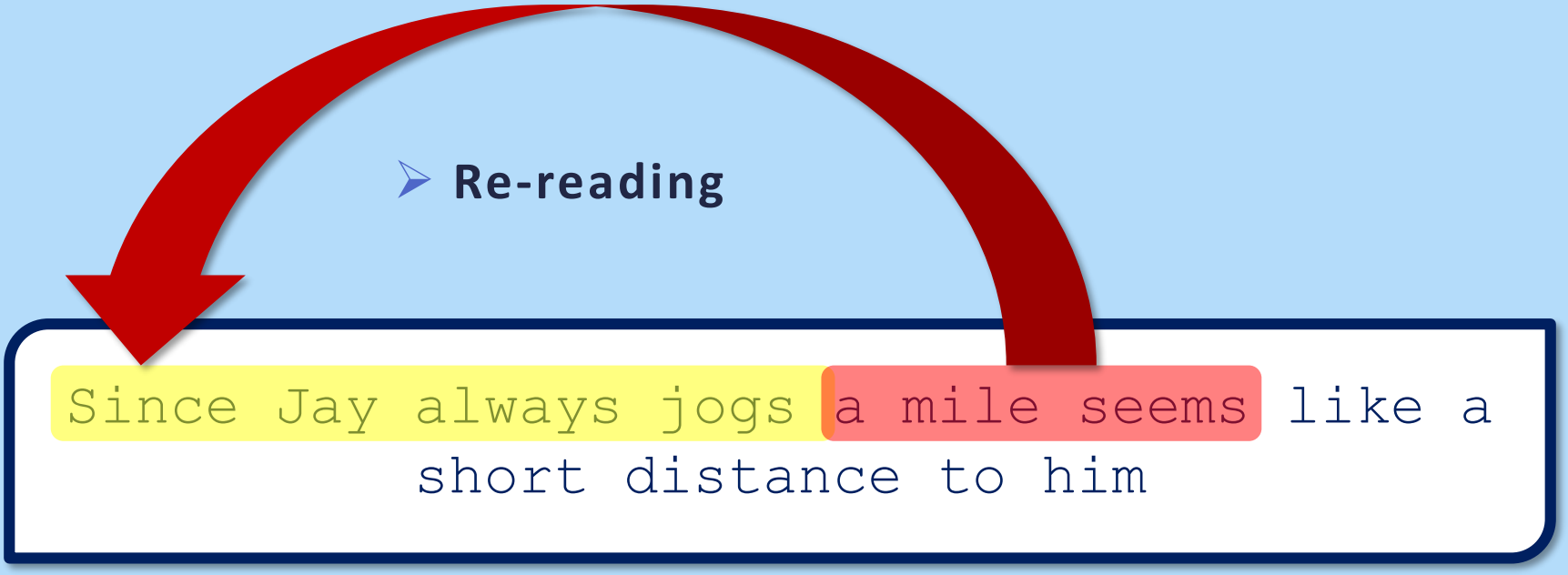


The city council

argued | the mayor's position | was incorrect

- **How** do humans **recover from mistakes**?

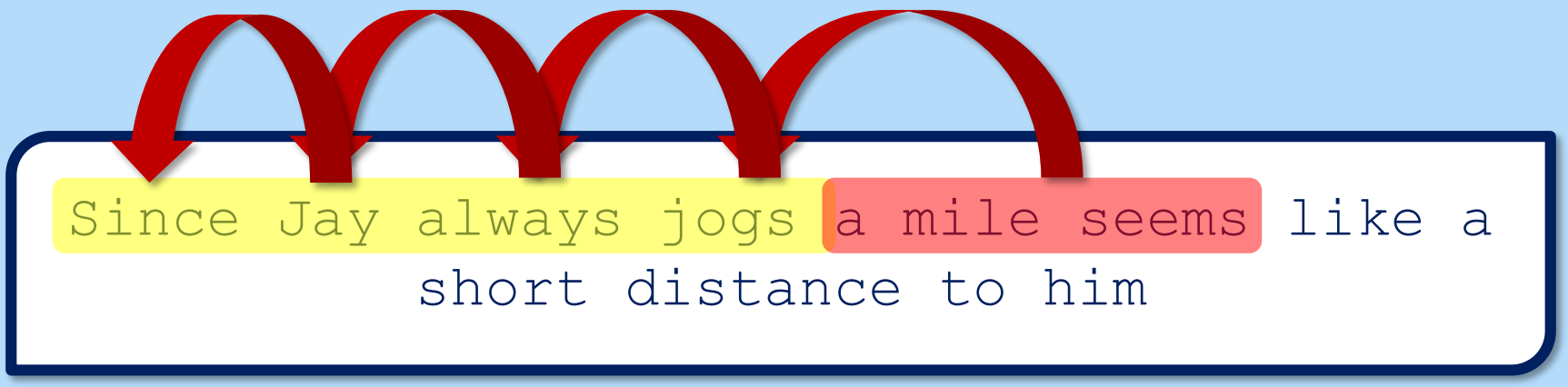
Garden-Path: Reanalysis Hypotheses [1]



1. **Forward Reanalysis Hp**.: back to the very **beginning** of the sentence

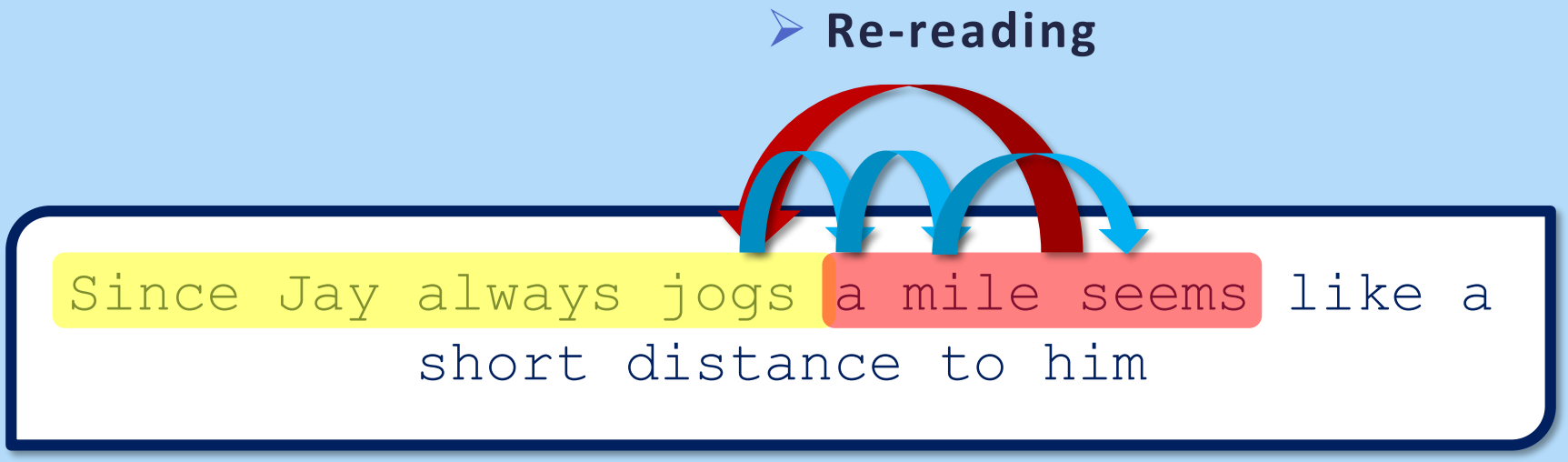
Garden-Path: Reanalysis Hypotheses [2]

- **Re-reading**



2. **Backward Reanalysis Hp.**: backward from the **point of breakdown**

Garden-Path: Reanalysis Hypotheses [3]



3. **Selective Reanalysis Hp.**: focus only on the **misleading portion**

- **How** do humans **understand sentences**?
- **How** do humans **deal with ambiguities**?
- **How** do humans **recover from mistakes**?

➢ How to **test** this?

The Experiment
– Method

Subjects

- # **16** Undergrads
  (**Within**-Sbj.)

Materials [1]

- **# 16 Closure** sentences; **4 versions**:
  - **Late** vs. **Early**
  - **Long** vs. **Short**

LC-Long: Since Jay always jogs **a mile and a half** **this** seems like a short distance to him.
EC-Long: Since Jay always jogs **a mile and a half** **seems** like a short distance to him.

LC-Short: Since Jay always jogs **a mile** **this** seems like a short distance to him
EC-Short: Since Jay always jogs **a mile** **seems** like a short distance to him

Materials [2]

- **# 16 Attachment** sentences; **4 versions**:
  - **Minimal** vs. **Non-Minimal**
  - **Long** vs. **Short**

MA-Long: I wonder if Tom heard **the latest gossip** about the new neighbours.
NM-Long: Tom heard **the latest gossip** about the new neighbours **wasn't true**.

MA-Short: I wonder if Tom heard **the gossip**.
NM-Short: Tom heard **the gossip wasn't true**.

Procedure

- **Eye-tracking** experiment:
  - **Self-paced reading** of whole sentences
  - Periodical **comprehension questions**
  - **2-hr** sessions per sbj. (too much?)

The Experiment

– Results and Discussion

Data Analysis

Data Analysis [1]

- **Measured** variables (Dep. Var.):

1. Total **Reading Time** per **Letter**

S_i_n_c_e__J_a_y__a_l_w_a_y_s__j_o_g_s__
...

Data Analysis [2]

- **Measured** variables (Dep. Var.):

2. Reading Time per Letter for **Different Regions**

- **Manipulated** variables (Indep. Var.):

➢ **ambiguous region**;

➢ **prior to the ambiguous region**;

➢ **disambiguating region**.

Since Jay always **jogs** **a mile** **seems** like a short distance to him

Data Analysis [4]

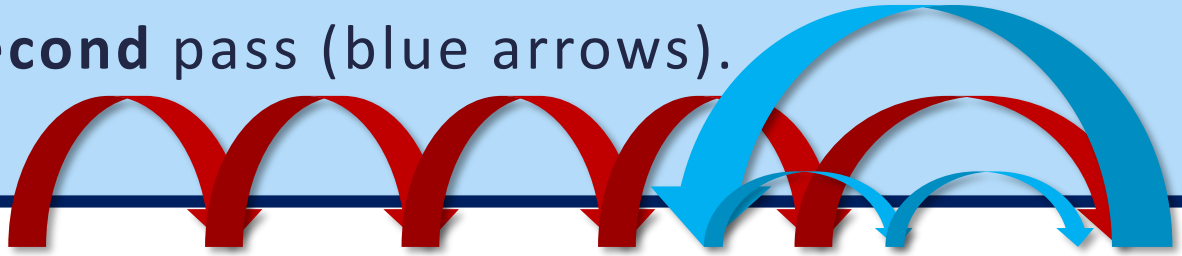
- **Measured** variables (Dep. Var.):

1. Total Reading Time per Letter
2. Reading Time per Letter for Different Regions

- Other **Manipulated** variables (Indep. Var.):

➢ **First** pass (red arrows);

➢ **Second** pass (blue arrows).



Since Jay always jogs a mile seems like a short distance to him

Data Analysis [5]

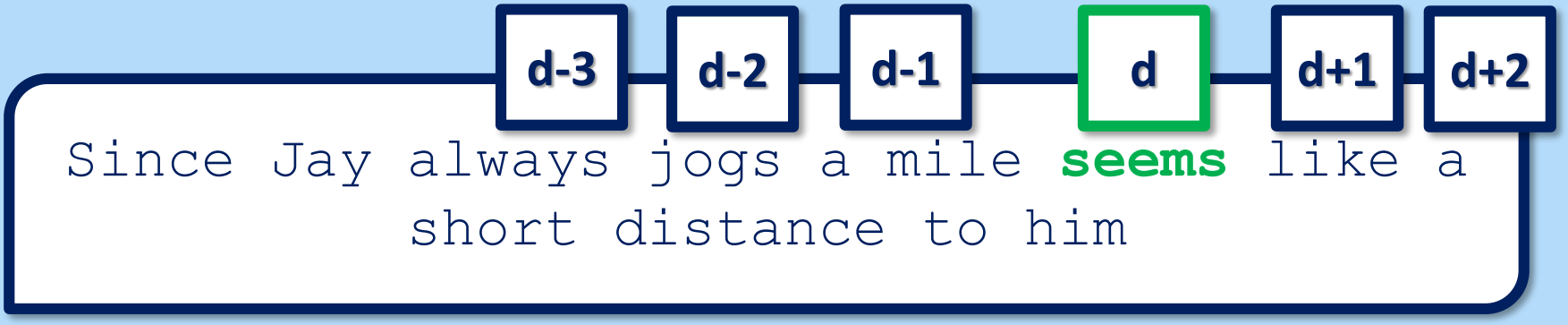
- **Measured** variables (Dep. Var.):

3. Average **Fixation Durations**

- **Manipulated** variables (Indep. Var.):

➢ **Last 3 fix.** prior to disambig. reg. (**d-1**, **d-2**, **d-3**);

➢ **First 3 fix.** in disambig. reg. (**d**, **d+1**, **d+2**).



Data Analysis [6]

- **Measured** variables (Dep. Var.):

4. Pattern of **Eye-movements** (regression frequency)

- **Manipulated** variables (Indep. Var.):

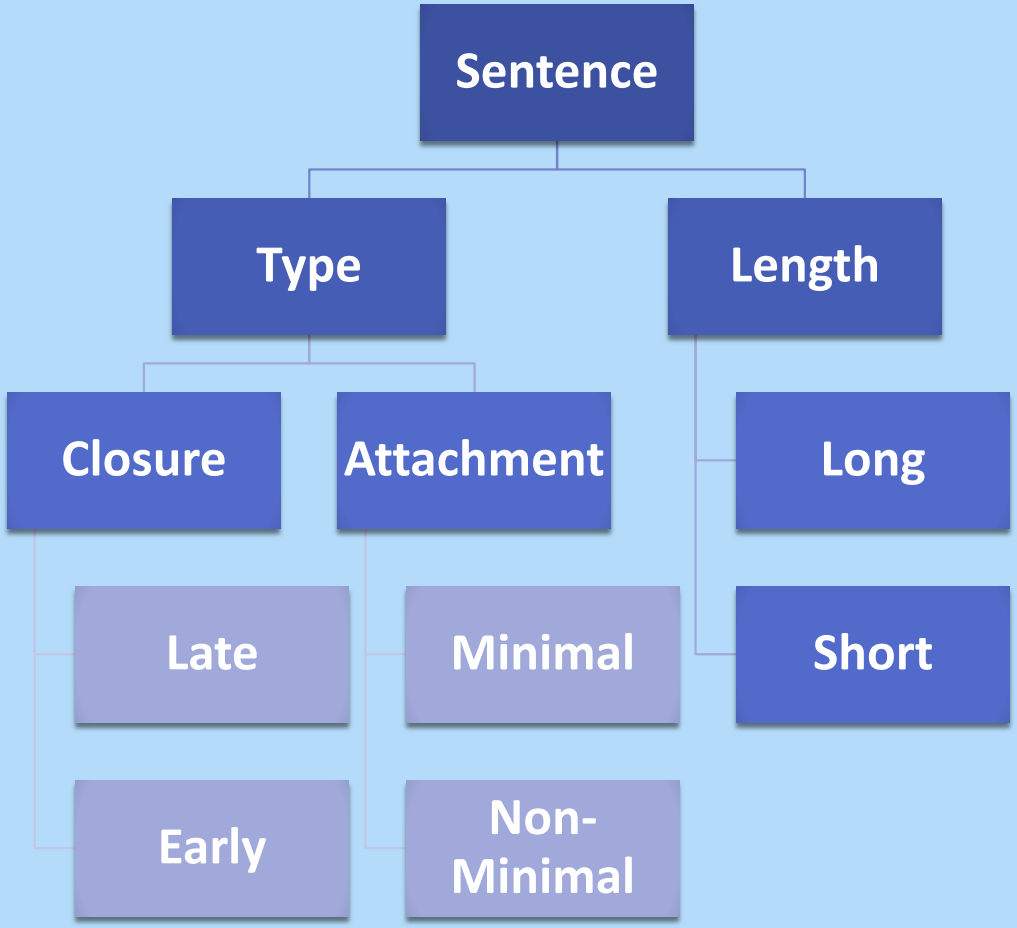
➢ **Region initiated from**;

➢ **Region ended to**.

Since Jay always **jogs** **a** **mile** **seems** like a short distance to him

Data Analysis [7]

- Plus! Other **Manipulated** variables (Indep. Var.):



Predictions

Predictions

- G-P Th. + related proc. strat. (LC, MA) **apply**:
  - Evidence: RTs for **EC** and **NM** **>** RTs for **LC** and **MA**
- EC and NM are **harder** to process:
  - Evidence: **Longer RTs** in or around disambig. reg.
- Ambiguity is **detected** if:
  - Evidence: **Longer RTs** in ambig. reg.
- **Selective Reanalysis** Hp. applies:
  - Evidence: **direct regr**. from disamb. to **ambig. reg**.

Results:
Closure Sentences

Results: Closure Sentences [1]

- 2 (**EC** vs. **LC**) × 2 (**Long** vs. **Short**) ANOVA on **Total Reading Time** per **Letter**

Mean Reading Time per Letter (msec) for Each of the Four Closure Sentence Versions

	Early closure	Late closure	$\bar{X}$
Long	68 (176)	50 (240)	59
Short	57 (211)	55 (218)	56
$\bar{X}$	62.5	52.5	

Note. Values in parentheses represent the estimated reading rate in words per minute based on an average word length of 5 characters.

Results: Closure Sentences [2]

- 2 (**Closure Type**) × 2 (**Length**) × 3 (**Region**) × 2 (**Pass**) ANOVA on **Reading Time** per **Letter** for **Regions**

Sentence type	Region of the sentence: Before ambiguity	Ambiguity	Disambiguation
Early closure–long			
1st pass	44	40	54
2nd pass	21	32	48
Total	65	72	102
Early closure–short			
1st pass	43	37	41
2nd pass	18	37	41
Total	61	74	82
Late closure–long			
1st pass	43	35	40
2nd pass	12	15	23
Total	55	50	63
Late closure–short			
1st pass	40	42	47
2nd pass	16	27	22
Total	56	69	69

Results: Closure Sentences [3]

- 2 (**Closure**) × 2 (**Length**) × 6 (**Serial Order Fix.**) ANOVA on **Average Fixation Durations**

Average Fixation Duration on the Three Fixations Prior to Reaching the Disambiguating Region (d) and the First Three Fixations in the Sentence Following the Initial Encounter with the Disambiguating Word

	Serial order of fixation					
Sentence type	1 (d − 3)	2 (d − 2)	3 (d − 1)	4 (d)	5 (d + 1)	6 (d + 2)
Early closure–long	252	259	236	301	285	313
Early closure–short	245	227	245	283	267	277
Late closure–long	248	239	243	260	247	242
Late closure–short	228	239	243	268	248	242

Note. These data were computed independent of the particular region of the sentence and consist only of the serial order that the fixations occurred in.

Results:
Attachment Sentences

Results: Attachment Sentences [1]

- 2 (**MA** vs. **NM**) × 2 (**Long** vs. **Short**) ANOVA on **Total Reading Time** per **Letter**

Reading Time per Letter (msec) for Each of the Four Attachment Sentence Versions

	Nonminimal attachment	Minimal attachment	$\bar{X}$
Long	61 (197)	45 (270)	53
Short	51 (235)	49 (246)	50
$\bar{X}$	56	47	

Note. Values in parentheses represent the estimated reading rate in words per minute based on an average word length of 5 characters.

Results: Attachment Sentences [2]

- 2 (**Att. Type**) × 2 (**Length**) × 2 (**Region**) × 2 (**Pass**) ANOVA on **Reading Time** per **Letter** for **Regions**

Sentence type	Region of the sentence: Before ambiguity	Ambiguity	Disambiguation
Nonminimal attachment – long			
1st pass	43	37	51
2nd pass	17	22	30
Total	60	59	81
Nonminimal attachment – short			
1st pass	43	36	47
2nd pass	10	15	23
Total	53	51	70
Minimal attachment – long			
1st pass	41	36	– –
2nd pass	7	7	– –
Total	48	43	– –
Minimal attachment – short			
1st pass	42	36	– –
2nd pass	8	12	– –
Total	50	48	– –

Results: Attachment Sentences [3]

- 2 (**Length**) × 6 (**Serial Order Fix.**) ANOVA on **Average Fixation Durations**

Average Fixation Duration on the Three Fixations Prior to Reaching the Disambiguating Region (d) and the First Three Fixations in the Sentence Following the Initial Encounter with the Disambiguating Word

	Serial order of fixation					
Sentence type	1 (d − 3)	2 (d − 2)	3 (d − 1)	4 (d)	5 (d + 1)	6 (d + 2)
Nonminimal attachment–long	248	259	258	291	284	301
Nonminimal attachment–short	247	235	226	292	280	267

Note. These data were computed independent of the particular region of the sentence and consist only of the serial order that the fixations occurred in.

Conclusions:
Closure & **Attachment**
Sentences

Conclusions: Closure & Attachment Sentences

- Closure Sent.: **Longer** RTs for **Disambig**. and **Ambig**. reg.

- Attach. Sent.: **Longer** RTs for **Ambig**. reg. on **second** pass

- Both: **Longer** average fixation durations for **Disambig**. reg. on **first** pass
  - Awareness of Ambiguity at that point.

Results:
Pattern
of **Eye-movements**

Results: Pattern of Eye-movements

- Cases of **longer** average **fixations** and **regressions**:

Matrix of the Region of the Sentence that a Regression was Initiated from and the Region of the Sentence that the Eye Movement Ended in

Regression Initiated from	Eye Movement Ended: Beginning of sentence	Before ambiguity	In ambiguity	In disambiguation	Total
Disambiguating region[b]	.03 (.01)[a]	.04 (.03)	.33 (.36)	.12 (.11)	.52 (.51)
After disambiguating region	.01 (.02)	.04 (.03)	.06 (.05)	.04 (.05)	.15 (.15)
End of sentence	.18 (.17)	.03 (.03)	.10 (.12)	.02 (.02)	.33 (.34)
Total	.22 (.20)	.11 (.09)	.49 (.53)	.18 (.18)	

Note. The values are proportions and are based on 222 regressions made by the subjects. The range of regressions was 5–29 per subject.
[a] The values in parentheses are for the early closure and nonminimal attachment sentences.
[b] In the minimal attachment sentences, the end of the sentence was considered to be the disambiguating region.

- Conclusions: **no evidence** for **backward** reanalysis

Frazier & Rayner (1982)

– Overall Findings

Overall Findings

- **G-P Th**. + related proc. strat. (**LC**, **MA**) **apply**:
  - Evidence: RTs for **EC** and **NM** **>** RTs for **LC** and **MA**
  - Consequence: **immediate** assignment of structure.

- **Selective Reanalysis** Hp. applies:
  - Evidence: **direct regr**. from disamb. to **ambig. reg**.
  - Consequence: **only revision of incompatible parts** having been previously assigned a (wrong) structure.

Reanalysis in Sentence Processing:
Evidence against Current Constraint-Based and Two-Stage Models

van Gompel, Pickering & Traxler (2001)

PART 2

Reading through the Decades:
Influential Papers in Psycholinguistics – Seminar

12/01/2016

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About **van Gompel et al. (2001)**
– Introduction and Background

- **How** do humans **understand sentences**?
- **How** do humans **deal with ambiguities**?
- **How** do humans **recover from mistakes**?

Three Orders of (Contrasting) **Models**

Distinctive Features

- **# of Interpretation/Analyses at once**:
  - **one** by one: **Serial/Two-stage** models;
  - **more** than one: **Parallel** models.

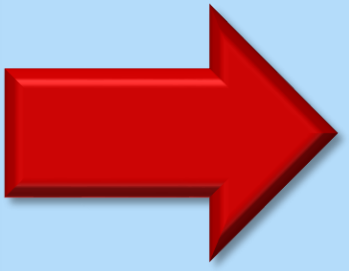
- **Type of Information Resources**:
  - first **syntax**, then **thematic** info;
  - **syntactic** and **thematic** info together.

- **Mechanism for Ambiguity resolution**:
  - **same** analysis: **Fixed-choice** two-stage models;
  - **different** analyses: **Variable-choice** two-stage models.

- **How** do humans **understand sentences**?

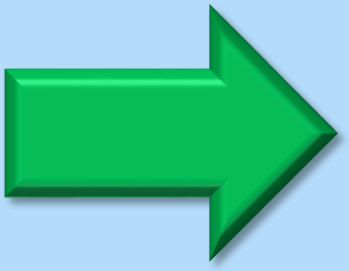
1. Two-Stage Models (e.g., Frazier & Rayner, 1982)

- **Serial** processing, **2** stages, **fixed**-choice:



➢ 1st stage

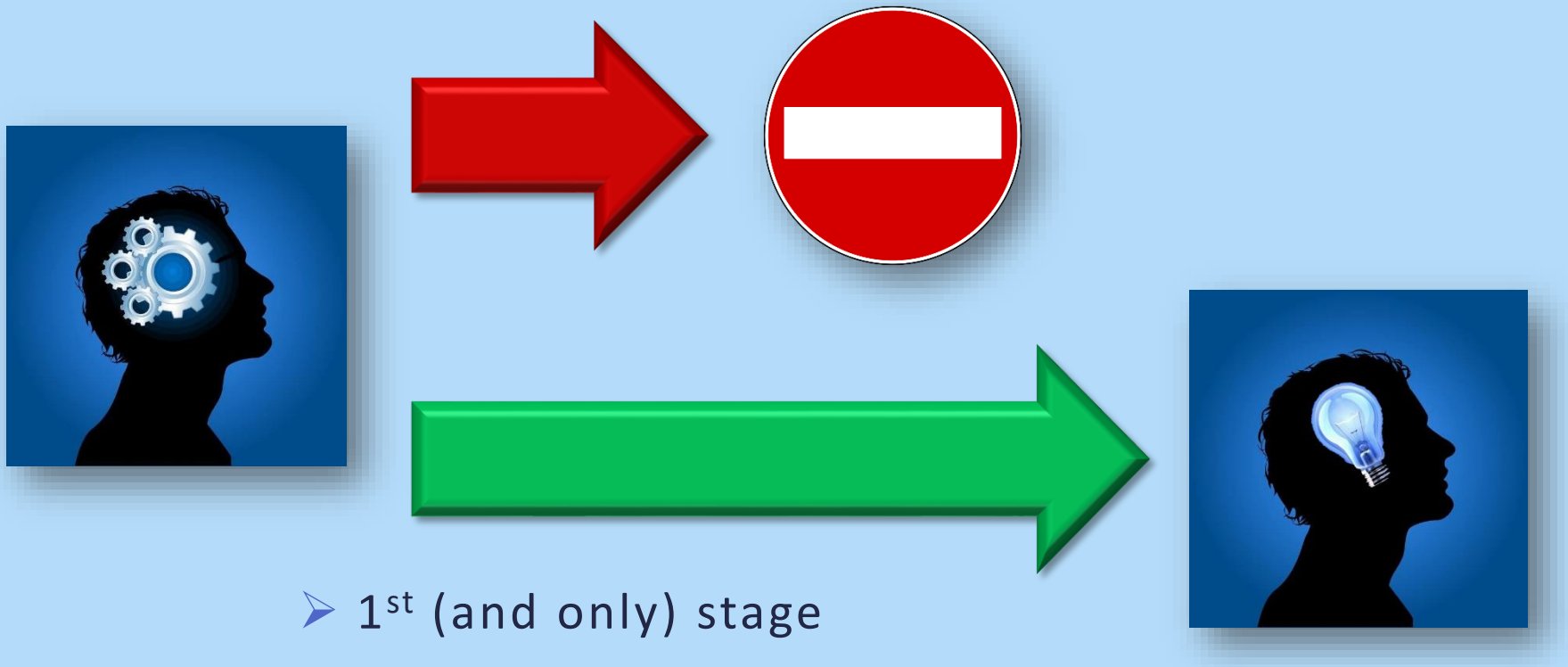
- 1st: based on **syntax** alone
- 2nd: use of **thematic** info, too



➢ 2nd stage

2. Constraint-Based Lexicalist Models (e.g., McRae et al., 1998)

- **Parallel** processing, **1** stage:



  - 1st (and only) stage

- Use both **syntactic** and **thematic** info together

3. Unrestricted Race Model (e.g., Traxler et al., 1998)

- '**Unrestricted**': use of **any sources** of info
- '**Race**': **parallel** structures engage in a race (fastest >> adopted)

- Reanalysis: **2** stages
- **Variable**-choice: strategies affected by **individual differences** and **source** of info

- **How** do humans **deal with ambiguities**?

1. Two-Stage Models: Ambiguity Resolution

- Deployed **strategies**:
  - **Late** Closure
  - **Minimal** Attachment

- Higher **Processing Difficulty**:
  - **Early** Closure
  - **Non-minimal** Attachment

2. Constraint-based Models: Ambiguity Resolution

- Deployed **strategies**:
  - **Multiple analyses** according to constraints

- Higher **Processing Difficulty**:
  - **initial** constr. favour analysis **A**, **later** constr. favour analysis **B**
  - **initial** constr. favour an. **A + B**, **later** constr. **do not** favour either

3. Unrestricted Race Model: Ambiguity Resolution

- Deployed **strategies**:
  - **Multiple analyses**

- Higher **Processing Difficulty**:
  - **initial** analysis **X**, but sentence is **disambiguated towards** analysis **Y**
  - **initial** analysis **Y**, but sentence is **disambiguated towards** analysis **X**

How did
van Gompel et al. (2001)
test Ambiguity?

van Gompel et al. (2001)

– Experimental Design

Two Experiments: Rationale

Experiment 1

- **VP-NP attachment Ambiguities**:
  - bias towards VP-att.

Experiment 2

- **VP-NP attachment Ambiguities**:
  - no initial bias

Experiments 1 & 2
– Method

Subjects

- Exp. **1**
- # **36** Uni-Studs

- Exp. **2**
- # **27** Uni-Studs

Materials (Exp. 1)

- # 30 VP-NP attach. like:

Ambig.: The hunter killed the dangerous poacher **with the rifle** not long after sunset.

VP-Att.: The hunter killed the dangerous leopard **with the rifle** not long after sunset.

NP-Att.: The hunter killed the dangerous leopard **with the scars** not long after sunset.

Materials (Exp. 2)

- # 30 VP-NP attach. like:

Ambig.: The hunter killed only the poacher **with the rifle** not long after sunset.

VP-Att.: The hunter killed only the leopard **with the rifle** not long after sunset.

NP-Att.: The hunter killed only the leopard **with the scars** not long after sunset.

Pretests (Exp. 1 & 2)

- **Plausibility** pretest:
  - rating of **how realistic** were different interpretations for each sentence;
  - **VP** plaus. for **VP**-att.; **NP** plaus. for **NP**-att; **VP**- and **NP**-att. both plaus. for Ambig.
- **Off-line preference** task:
  - tested **items' bias** (preference for attach. **PP** to **VP** or **NP**)
  - Exp. **1**: bias towards **VP**; Exp. **2**: **no** bias.
- **Completion** task:
  - testing bias by **completing PP** with meaningful continuation;
  - Exp. **1**: bias towards **VP**; Exp. **2**: **no** bias.

Procedure (Exp. 1 & 2)

- **Eye-tracking** experiment:
  - **Self-paced reading** of whole sentences
  - Periodical **comprehension questions**
  - **30-min** sessions per sbj. (much better)

Experiments 1 & 2

– Results and Discussion

Data Analysis

Data Analysis (Exp. 1 & 2)

- **Measured** variables (Dep. Var.):

1. **Fixation Times** for **Different Regions** (7 in total)

- **Manipulated** variables (Indep. Var.):

- Reg. 1, **Sbj NP**;
- Reg. 2, **V**;
- Reg. 3, **Obj NP**;
- Reg. 4, "*with the*";
- Reg. 5, **critical noun region** (PP's **N**);
- Reg. 6, postcritical region (**AdvP**).

Data Analysis (Exp. 1 & 2)

- **Measured** variables (Dep. Var.):

1. **Fixation Times** for **Different Regions**

- **Manipulated** variables (Indep. Var.):

- **First-pass time**: all fixations on a region for **1st time**;
- **Firs-pass regression**: all **repeated** leftward fixations for **2nd** time ;
- **Regression-path time**: all (first) fixation times within the **same region**.
- **Total time**: sum of **all** (first and second) **fixations** within the **same region**.

Results:
Experiment 1

Results (Exp. 1)

- Mean **Reading Times** and Percentage of **Regressions**

	Region						
	1 The hunter	2 killed	3 the dangerous poacher	4 with the	5 rifle	6 not long after	7 sunset
First-pass reading times							
Ambiguous	502	378	672	300	374	500	565
VP attachment	491	357	683	305	376	509	553
NP attachment	490	370	656	302	373	543	539
First-pass regressions							
Ambiguous		5.0	14.0	6.0	8.8	11.3	42.7
VP attachment		6.5	6.6	3.9	11.4	11.4	52.1
NP attachment		7.8	10.0	3.6	12.2	25.8	51.2
Regression-path times							
Ambiguous	502	417	818	354	420	684	1198
VP attachment	491	401	748	330	444	663	1252
NP attachment	490	408	750	328	431	841	1491
Total times							
Ambiguous	622	532	947	379	451	699	698
VP attachment	593	476	890	394	468	721	663
NP attachment	619	529	922	459	567	829	685

Note. First pass, regression path, and total times are reported in milliseconds and first-pass regressions as the percentage of saccades leaving the region to the left after a first-pass fixation.

Results:
Experiment 2

Results (Exp. 2)

- Mean **Reading Times** and Percentage of **Regressions**

	Region						
	1 The hunter	2 killed	3 only the poacher	4 with the	5 rifle	6 not long after	7 sunset
First-pass reading times							
Ambiguous	371	331	520	265	310	448	464
VP attachment	398	315	555	272	317	463	479
NP attachment	405	312	560	286	314	442	491
First-pass regressions							
Ambiguous		6.2	9.0	6.8	15.6	13.9	59.1
VP attachment		9.8	9.0	7.4	17.1	22.1	56.4
NP attachment		6.5	9.5	9.1	14.3	27.1	61.1
Regression-path times							
Ambiguous	371	363	620	299	360	562	1063
VP attachment	398	374	626	332	379	693	1172
NP attachment	405	342	645	342	377	682	1133
Total times							
Ambiguous	421	425	706	362	398	633	595
VP attachment	469	435	795	409	404	681	597
NP attachment	456	412	764	410	432	674	611

Note. First pass, regression path, and total times are reported in milliseconds and first-pass regressions as the percentage of saccades leaving the region to the left after a first pass fixation.

Van Gompel et al. (2001)

– Overall Findings

Overall Findings

- **Exp. 1**:
  - Predictions: preference for **VP**-att.
  - Evidence: RTs (on regressions) for **NP-att.** > RTs for **VP-att.** and **Ambig.**
  - Consequence: consistent with **G-P Th.** and **URM**.
- **Exp. 2**:
  - Predictions: no preference for either NP- or VP-att. (more strategies as in variable-choice models)
  - Evidence:

1) RTs for **NP- & VP-att.** > RTs for **Ambig.**

2) No pref. for either NP- or VP-att.

  - Consequence: consistent with **URM**.

Frazier & Rayner (1982)
Van Gompel et al. (2001)
– The Three Models Compared

Garden-Path Model	Constraint-Based Model	Unrestricted Race Model
Serial/Two-Stage (no compet., but rean.)	**Parallel** (competition)	**Parallel** (competition)
Fixed-choice	–	**Variable-choice**
Resources: First **syntax**, then **thematic**	Resources: **Syntactic** + **thematic**	Resources: **Various**
Strategies: **LC** & **MA**	Strategies: **Multiple**	Strategies: **Multiple**
Proc. Difficulty: **EC** & **NM**	Proc. Difficulty: **Ambig**. conditions	Proc. Difficulty: **Disambig**. conditions
Preference: **VP-attach**.	Preference: **None** (initially)	Preference: **50:50** (VP, NP)

- **Who** wins??

Who wins??

Thanks for your kind attention!