Online Processing at the Syntax-Semantics Interface – Evidence from Scope Interaction in German

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Representations are built from left to right in close temporal contiguity to the input signal.

globally (eg. Frege, 1884)
Never [...] ask for the meaning of a word in isolation, but only in the context of a proposition.

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Linguistic Representations Are Constructed... 

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Overview

1. Introduction – Incrementality in Syntax and Semantics

2. Reconstruction of Fronted Object Quantifiers
   - Pretests
   - Scope Inversion Effects during Online Comprehension

3. Incremental Effects of Scope Interaction without Reconstruction

4. Conclusions
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(1) Die Prinzessin malt die Königin.
The princess\textit{subject/object} paints the queen\textit{object/subject}.
Incremental Disambiguation Via Syntactic Information

Schlesewsky et al. (2000, Exp. 2), self-paced reading:

(2a) \textit{Welche Frauen} \textsubscript{1} \textit{sah} \textsubscript{2} \ldots
Which women\textit{object} saw\textit{sing}. \ldots

(2b) \textit{Welche Frauen} \textsubscript{1} \textit{sahen} \textsubscript{2} \ldots
Which women\textit{subject} saw\textit{pl}. \ldots

\[\text{Segment} \quad 1 \quad 2 \quad 3 \quad 4 \quad 5\]

\begin{tabular}{lccccc}
\hline
 & \textit{which} & \textit{NP}_{pl} & \textit{V}_{sg/pl} & \textit{NP2} & \textit{PP} & ? \\
verb=sg. Wh=acc & 987 & 845 & 805 & 973 & 811 \\
verb=pl Wh=nom & 1015 & 650 & 751 & 943 & 752 \\
\hline
\end{tabular}

\[\text{\textgreater{} Syntactic reanalysis: } \textit{subject} + \textit{verb} \rightsquigarrow \textit{object} + \textit{verb}\]
Knöferle et al. (2005, Exp. 1), visual-world paradigm:

(3) Die Prinzessin malt offensichtlich . . .
   The princess \textit{subject/object} paints apparently . . .

A) princess = patient, \textit{OVS}:

B) princess = agent, \textit{SVO}:
 Participants are able to semantically interpret *subject + transitive verb* and revise the structure if it does not fit the context without a syntactic cue.
Incremental Parsing

(4a) Die Prinzessin malt die Königin.
The princess_{subject/object} paints the queen_{object/subject}.

(4b) Die Prinzessinnen _malt_ die Königin.
The princesses_{object} paints the queen_{subject}.

(4c) visual context: the queen paints the princess.
Die Prinzessin _malt_ die Königin.
The princess_{object} paints the queen_{subject}.

Incremental Syntactic Reconstruction: \( SO \leadsto OS \)
- Syntactic cue disambiguates (4b)
- Event information disambiguates (4c)
Heim & Kratzer style analysis of a yet incomplete sentence with *subject + verb*:

The princess <e,<e,t>> paints . . .

Because semantic analysis proceeds in a global fashion, compositional interpretation is not possible for partial structures like these.

However, the just described studies show that *subject + verb* is composed immediately.

Barker style analysis of *the princess paints*:

\[
\begin{array}{c}
\text{the princess} \\
\text{paints} \\
\text{NP}
\end{array}
\] = \([\text{NP}] (\lambda x [\text{paint}(\text{the princess}, x)])
\]
Is Semantic Interpretation Incremental Throughout?

- The *subject* + *transitive verb* case is one of the simplest case of non-constituent composition we can think of. Does word-by-word interpretation generalize to other, compositionally more complex cases than thematic interpretation?

Different general cognitive conditions for syntactic and semantic interpretation?

- Working memory constraints enforce immediate structural integration
- The semantic processor may suffer less pressure because the input is already integrated structurally
- Is semantic interpretation, like syntactic processing, incremental throughout?
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Two Test Cases

We address the incrementality of the online composition of meaning in the absence of overt syntactic ambiguity. In particular, we will consider:

- Scope reconstruction of fronted object quantifiers:

  (5a) Jeden seiner Schüler hat genau ein Lehrer …
      Each of his pupils object AUX exactly one teacher subject …
      ’Exactly one teacher AUX each of his pupils …’

- Scope interaction without scope reconstruction:

  (5b) Mehr als die Hälfte der Mitarbeiter haben nicht …
      ’More than half of the staff AUX not …’

- Both cases are problematic for Heim & Kratzer style analyses
- Barker-style analyses can deal with all sorts of incomplete sentences
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Reconstruction Without Syntactic Reanalysis

(6) Jeden seiner Schüler lobte genau ein Lehrer. Each of his pupils praised exactly one teacher. ’Exactly one teacher praised each of his pupils.’

The example exhibits some interesting features:

- OVS order with a case disambiguated object quantifier, thematic fit (teachers should praise their pupils)
- Variable binding of his only in the inverse reading (6b), but not in (6a)
- Therefore, the object quantifier has to undergo scope reconstruction

\[
(6a) \quad \forall x((PUPIL(x) \land OF(x, y)) \rightarrow \exists! z(TEACHER(z) \land PRAISE(z, x)))
\]

\[
(6b) \quad \exists! y(TEACHER(y) \land \forall x((PUPIL(x) \land OF(x, y)) \rightarrow PRAISE(y, x)))
\]
Immediate Reconstruction Of Quantifiers?

(6) Jeden seiner Schüler ...
Each of his pupils

\[ \forall x : pupil\ (x, y) \rightarrow \ldots \]

Something happens to each of y’s pupils
Immediate Reconstruction Of Quantifiers?

(6) Jeden seiner Schüler hat genau ein Lehrer ...
Each of his pupils has exactly one teacher ...

\[ \forall x : pupil of(x, y) \rightarrow \exists! z : teacher(z) \land \ldots \]

- Apply quantifier hierarchy to compute rel. weight of QPs
- Linear scope \( \forall \exists! \) is preferred
Immediate Reconstruction Of Quantifiers?

(6) Jeden seiner Schüler hat genau ein Lehrer ...  
Each of his pupils\(_{DO}\) has exactly one teacher ...

\[ \exists!z : teacher(z) \land \forall x : pupil\ of(x, z) \rightarrow \ldots \]

- Check variable binding
  - Linear scope cannot be maintained, object quantifier has to undergo scope reconstruction (\(\triangleright \exists!\forall\))
Is The Verbal Predicate Required?

(6) Jeden seiner Schüler hat genau ein Lehrer voller Stolz...
Each of his pupils has exactly one teacher full of pride...

In sentences like (6) we can test whether readers invert scope immediately when they encounter a second quantifier – that is before they even know what kind of situation is being described!
Is The Verbal Predicate Required?
Hendriks 1993 vs. Barker 2002

(7) Genau ein Lehrer wird jeden Schüler . . .
   Exactly one teacher will every student . . .

Hendriks (1993)’s flexible verb types approach:

- Scope depends on interpretive schema of the verb:
  \[
  \lambda Q_2 . \lambda Q_1 . Q_1 (\lambda y. Q_2 (\lambda x. P(x)(y)))
  \]
  (linear scope)
  \[
  \lambda Q_2 . \lambda Q_1 . Q_2 (\lambda y. Q_1 (\lambda x. P(x)(y)))
  \]
  (inverse scope)

Barker (2002)’s continuation semantics:

- Can handle scope independently of the verb:
  \[
  \lambda p . \exists! y [\text{TEACHER}(y) \land \forall x [\text{STUDENT}(x) \rightarrow p]]
  \]
  (linear scope)
  \[
  \lambda p . \forall x [\text{STUDENT}(x) \rightarrow \exists! y [\text{TEACHER}(y) \land p]]
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Barker (2002)'s continuation semantics:

- **Can handle scope independently of the verb:**
  \[
  \lambda p . \exists! y [\text{TEACHER}(y) \land \forall x [\text{STUDENT}(x) \to p]]
  \]
  \[
  \lambda p . \forall x [\text{STUDENT}(x) \to \exists! y [\text{TEACHER}(y) \land p]]
  \]
  (linear scope)
  (inverse scope)
Incremental scope reconstruction:

- Verb independent: quantifiers immediately undergo scope reconstruction if required, independently of the verbal predicate
- Verb dependent: quantifiers only undergo reconstruction once the verbal predicate has been encountered

Global interpretation:

Scope reconstruction is a last resort and is only considered at the end of the sentence.
Design Of The Study

8) Jeden seiner Schüler lobte genau ein Lehrer voller Wohlwollen.  
[Q-V-Q/+his]
Each of his pupils was praised by exactly one teacher full of goodwill.

9) Jeden dieser Schüler lobte genau ein Lehrer voller Wohlwollen.  
[Q-V-Q/–his]
Each of these pupils was praised by exactly one teacher full of goodwill.

10) Jeden seiner Schüler hat genau ein Lehrer voller Wohlwollen gelobt.  
[Q Aux Q/+his]
Each of his pupils was by exactly one teacher full of goodwill praised.

11) Jeden dieser Schüler hat genau ein Lehrer voller Wohlwollen gelobt.  
[Q Aux Q/–his]
Each of these pupils was by exactly one teacher full of goodwill praised.
Predictions

**Incremental Scope Interpretation Hypothesis (ISH)**

Processing difficulty due to a revision of scope shows up immediately at the second quantifier even when the sentence isn’t complete yet. Two variants:

- **VERB INDEPENDENT**: difficulty at the 2nd QP irrespective of the position of the main verb.

- **VERB DEPENDENT**: difficulty at the 2nd QP in Q-V-Q/+his; in Q-Aux-Q/+his, difficulty delayed until the main verb

**Global Interpretation Hypothesis (GIH)**

Processing difficulty due to a revision of scope shows up only at the end of the sentence.
Implicit Assumptions

Assumption 1
In the construction under investigation linear scope is preferred over inverse scope.

Assumption 2
When encountering a cataphoric pronoun, binding is preferred over a coreferential interpretation.

Assumption 3
Computing a bound interpretation is not difficult per se.

-we conducted three pretests to justify these assumptions
Each of these pupils was praised by exactly one teacher.

Is (11) really ambiguous?

Is there a preference for linear scope?
Assumption 1 – Truth Value Judgment Task

(11) Jeden dieser Schüler lobte genau ein Lehrer.
    Each of these pupils was praised by exactly one teacher.

(12) Auf jeden dieser Schüler trifft zu, dass ihn genau ein Lehrer lobte.
    Each of these pupils is such that he was praised by exactly one teacher.
Confirming Assumption 1

- Condition (11) is in fact ambiguous as shown by smaller difference with disambiguated condition (12)
- Strong preference for linear scope (Assumption 1)
(14) Peter$_i$ is the class teacher of class 5a. Yesterday at the teacher’s meeting he was very surprised. Each of his$_i$ pupils was praised full of goodwill by at least one teacher. This he hadn’t expected.

- *His pupils = Peter’s pupils*
- Do comprehenders interpret the possessive pronoun coreferentially?
(14) Peter\textsubscript{i} is the class teacher of class 5a. Yesterday at the teacher’s meeting he was very surprised. Each of his\textsubscript{i} pupils was praised full of goodwill by at least one teacher. This he hadn’t expected.

- *His pupils = Peter’s pupils*

- Do comprehenders interpret the possessive pronoun coreferentially?
Assumption 2 – A Paraphrase Selection Task

+his) Jeden seiner Schüler lobte genau ein Lehrer.
Each of his pupils was praised by exactly one teacher.

-his) Jeden dieser Schüler lobte genau ein Lehrer.
Each of his pupils was praised by exactly one teacher.

Paraphrases in the condition with a possessive pronoun:

1. Bound variable interpretation with reconstructed quantifier
2. Sentence external coreferential int. with linear scope
3. Sentence external coreferential int. with inverse scope

Task:
Choose among the set of three paraphrases
Assumption 2 – A Paraphrase Selection Task

- *his*: preference for linear scope
- *+ his*: bound interpretation
- *+ his*: reconstruction

![Graph showing percentage of chosen paraphrases for different interpretations](chart.png)
Assumption 3 – The Bound Interpretation Is Not Difficult Per Se

QQ/+his)  \exists! x[teacher(x) \land \forall y[pupil\_of(y)(x) \rightarrow praise(x)(y)]]

QQ/–his)  \exists! x[teacher(x) \land \forall y[pupil(y) \rightarrow praise(x)(y)]]

The construction/evaluation of models like these may differ between [QQ/+his] and [QQ/–his]
Assumption 3 – The Bound Interpretation Is Not Difficult Per Se

QQ/+his) $\exists! x [teacher(x) \land \forall y [pupil_{of}(y)(x) \to praise(x)(y)]]$

QQ/–his) $\exists! x [teacher(x) \land \forall y [pupil(y) \to praise(x)(y)]]$

▶ The construction/evaluation of models like these may differ between [QQ/+his] and [QQ/–his]
Assumption 3 – No Difference In Reading Times

+his) Genau ein Lehrer lobte jeden seiner Schüler | . . .
  Exactly one teacher praised each of his pupils | . . .

-his) Genau ein Lehrer lobte jeden dieser Schüler | . . .
  Exactly one teacher praised each of these pupils | . . .

Both conditions were read equally fast

Once the LF of the bound inverse reading is computed, difficulty is the same as in [QQ/–his]
Eyetracking Study – Doubly Quantified Sentences

1) Jeden seiner Schüler | lobte | genau ein Lehrer | voller | Wohlwollen. [Q-V-Q/+his]
   Each of his pupils$_{DO}$ was praised by exactly one teacher full of goodwill

2) Jeden dieser Schüler | lobte | genau ein Lehrer | voller | Wohlwollen. [Q-V-Q/–his]
   Each of these pupils$_{DO}$ was praised by exactly one teacher$_{Subj.}$ full of goodwill

3) Jeden seiner Schüler | hat | genau ein Lehrer | voller | Wohlwollen | gelobt. [Q-Aux-Q/+his]
   Each of his pupils$_{DO}$ was by exactly one teacher$_{Subj.}$ full of goodwill praised

4) Jeden dieser Schüler | hat | genau ein Lehrer | voller | Wohlwollen | gelobt. [Q-Aux-Q/–his]
   Each of these pupils$_{DO}$ was by exactly one teacher$_{Subj.}$ full of goodwill praised
5) Jeden seiner Schüler | lobte | der neue Lehrer | voller | Wohlwollen. 

Each of his pupils\textsubscript{DO} was praised by the new teacher full of goodwill

6) Jeden dieser Schüler | lobte | der neue Lehrer | voller | Wohlwollen. 

Each of these pupils\textsubscript{DO} was praised by the new teacher\textsubscript{Subj}. full of goodwill

7) Jeden seiner Schüler | hat | der neue Lehrer | voller | Wohlwollen | gelobt. 

Each of his pupils\textsubscript{DO} was by the new teacher\textsubscript{Subj}. full of goodwill praised

8) Jeden dieser Schüler | hat | der neue Lehrer | voller | Wohlwollen | gelobt. 

Each of these pupils\textsubscript{DO} was by the new teacher\textsubscript{Subj}. full of goodwill praised
Within design: 2 verb position (Q-V-Q vs. Q-Aux-Q) x 2 DP type (QQ vs. QDef) x 2 pronoun (his vs. these)

- 48 participants
- Same regions of interest as in Exp. 1a/b
- Analysis: a) First-pass times, b) regression path durations, c) second-pass times, proportions of d) regressions out and e) regressions into a region
- 40 items + 118 fillers (52 nonsensical)
- Sensicality judgment after each trial
- 8 lists in a latin square design
The knight attacked the windmill on his donkey.

Reported eyetracking measures:

- First-pass times
- First-pass regression ratios
- Regression path duration
Surprisingly . . .

. . . we didn’t find any effects of *verb position*, so in the following we will report the aggregated data over *Q-V-Q* and *Q-Aux-Q* sentences.
First-Pass Times

- Early effect (\textit{DP type*pronoun} interaction) at 2nd QP
- Incremental scope assignment?
Sentence final ROI: 1) QQ conditions led to more regressions than controls, 2) more regressions out of [QQ/+his] than [QQ/–his]

Scope interpretation delayed until the end of the sentence
Sentence final ROI: 1) QQ conditions led to more regressions than controls, 2) more regressions out of [QQ/+his] than [QQ/–his]

Scope interpretation delayed until the end of the sentence
Sentence final ROI: 1) QQ slower than QDef, 2) scope inversion effect

Scope computation during rereading of the doubly quantified sentences
Sentence final ROI: 1) QQ slower than QDef, 2) scope inversion effect

Scope computation during rereading of the doubly quantified sentences
Does The Early Effect Index Scope Reconstruction?

If so, we would expect the early effect to be negatively correlated with the effects at the sentence final ROI

individual trials [QQ/+his]:

[QQ/+his – QQ/–his] per part.:

- Early and late effects are not significantly correlated

R² Linear = 0.002
Discussion

Early effect:
- Failed search for a binder

Late effect:
- Interaction $DP\text{ type}^*pronoun$: Scope reconstruction
- Main effect of $DP\text{ type}$: Constructing a model for a QQ sentence may be more difficult than constructing a model for a QDef sentence

**GLOBAL INTERPRETATION:**
Scope reconstruction is a last resort and is only considered at the end of the sentence.

In a self-paced reading experiment using the same design and materials, we also found delayed scope reconstruction effects only at the end of the sentence.
Discussion

Early effect:
- Failed search for a binder

Late effect:
- Interaction $DP\ type^{*}pronoun$: Scope reconstruction
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Can The Findings Be Generalized Beyond Scope Reconstruction?

- **INCREMENTAL SCOPE INTERPRETATION** only tested with respect to scope reconstruction

  ▶ What about interpretation of relative scope in general?
  ▶ Presented data leave open two possibilities:

1. **GLOBAL INTERPRETATION** applies to scope interpretation in general

2. **INCREMENTAL SCOPE INTERPRETATION** of linear scope, but scope reconstruction subject to **GLOBAL INTERPRETATION**
Idea to test **INCREMENTAL INTERPRETATION** further

- Manipulate semantic complexity of scope-taking operators to find out whether they are composed incrementally

<table>
<thead>
<tr>
<th>combination</th>
<th>processing cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>... $O_1 \ldots O_2 \ldots$</td>
<td>$\alpha$ (baseline)</td>
</tr>
<tr>
<td>... $O_1 \ldots O_2 \ldots$</td>
<td>$\alpha + \beta_1$ (additional cost $O_1$)</td>
</tr>
<tr>
<td>... $O_1 \ldots O_2 \ldots$</td>
<td>$\alpha + \beta_2$ (additional cost $O_2$)</td>
</tr>
<tr>
<td>... $O_1 \ldots O_2 \ldots$</td>
<td>$\alpha + \beta_1 + \beta_2 + \gamma$ (combined cost $O_1 &amp; O_2$)</td>
</tr>
</tbody>
</table>

If combined processing cost surpasses sum of individual costs (over-additive effects), this can be used as marker for semantic composition!
Candidate Manipulation: Direction of Entailment

- **Direction of entailment** intuitively produces over-additive effects:
  
  (1)  
  a. At least one boy tickled more than two girls.  
  b. At most one boy tickled more than two girls.  
  c. At least one boy tickled fewer than one girls.  
  d. At most one boy tickled fewer than one girls.  

- However, (1-d) may be so complex that composition does not succeed (cf. Bott et al. 2013)

- Somewhat simpler combination: quantifier and negation

  (2) Less than half of the staff did not study in the USA.
Pilot Study: Establishing Over-Additive Effects

- In an eyetracking experiment, 48 participants read 32 (8 per condition) German sentences like:
  
  (3) Auf Q Kreuze trifft zu, dass sie (nicht) blau sind.  
  On Q crosses holds that they (not) blue are.  
  ’Q cross(es) are such that they are (not) blue.’

- Manipulation: *direction of entailment* (UE vs. DE) × *negation* (absent vs. present)

  - Q ∈ \{ mehr als die Hälfte der (’more than half of the’),  
    weniger als die Hälfte der (’less than half of the’) \}

- Negation appeared in clause-bound position to exclude possibility of scope reconstruction

- Afterwards, participants performed sentence-picture verification
Main result: Direction of entailment and negation affect reading times over-additively (interaction: GLME: \( t = 2.78 \); model comparison: \( \chi^2(1) = 7.69, p < .01 \))

Manipulation well-suited as marker of semantic composition to test INCREMENTAL SCOPE INTERPRETATION
Planned Eyetracking Study

(4) Mehr als die Hälfte der Kollegen studierten (nicht) in den USA.
Less than half of the colleagues studied (not) in the USA.
‘Less than half of the colleagues did (not) study in the USA.’

(5) Weniger als die Hälfte der Kollegen studierten (nicht) in den USA.
Less than half of the colleagues studied (not) in the USA.
‘Less than half of the colleagues did (not) study in the USA.’

(6) Mehr als die Hälfte der Kollegen haben (nicht) in den USA studiert.
Less than half of the colleagues have (not) in the USA studied.
‘Less than half of the colleagues did (not) study in the USA.’

(7) Weniger als die Hälfte der Kollegen haben (nicht) in den USA studiert.
Less than half of the colleagues have (not) in the USA studied.
‘Less than half of the colleagues did (not) study in the USA.’

Manipulation: verb position (V2 vs. VLast) \times direction of entailment (UE vs. DE) \times negation (absent vs. present)
Especially with rise-fall intonation, scope reconstruction may take place (e.g. Büring 1997)

Truth-value judgment to condition on linear interpretation

(8) More/Less than half of the staff did not study in the US.

<table>
<thead>
<tr>
<th>A: US</th>
<th>B: Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>C: Europe</td>
<td>D: US</td>
</tr>
<tr>
<td>E: Europe</td>
<td>F: US</td>
</tr>
<tr>
<td>G: US</td>
<td>H: Europe</td>
</tr>
</tbody>
</table>

\[ Q \not\dashv \ X \quad \neg Q \checkmark \]
(9) More/Less than half of the staff studied/did not study in the US. (V-last vs. V-2)

Predictions:

**INCREMENTAL INTERPRETATION**
- Irrespective of *verb position*, composition takes place immediately
- Combined processing cost of *direction of entailment* and *negation* detectable as soon as negation is encountered
- Two-way but no three-way interaction.

**GLOBAL INTERPRETATION**
- Composition delayed until main verb is encountered
- Three-way interaction of *verb position* × *direction of entailment* × *negation*
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- To our surprise, we didn’t find any evidence for incremental interpretation of scope reconstruction.

- But: Under which circumstances would we ever utter a sentence with a fronted object quantifier which has to undergo reconstruction, again?
  - What are the licensing conditions, information structurally?
  - Do we find such sentences in corpora?

- To get a better understanding of the time course of scope interpretation, the findings of the planned experiment will be important.

- If scope is processed globally in general, we will have to think about a semantic theory that assigns thematic roles incrementally (Knöferle et al. 2005) while leaving scope temporarily unspecified.
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Thank you very much for your attention!