Delayed interpretation of quantifier scope – Evidence from eyetracking during reading

Oliver Bott (joint work with Fabian Schlotterbeck)
Project CiC, XPrag.de & Project B1, SFB 833, Tübingen

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Linguistic Representations Are Constructed…

incrementally (eg. Hagoort, 2006)

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.
Overview

1. Introduction – Incrementality in Semantic Interpretation

2. Scope Reconstruction (Bott & Schlotterbeck, 2015)
   - Pretests
   - Scope Inversion Effects during Online Comprehension

3. Scope Interaction without Reconstruction
   - Effects of Quantificational Complexity in Linear Readings
   - Future Steps: Cleft Sentences and Context Effects

4. Conclusions
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Incremental Semantic Interpretation Challenges

Semantic Theories

- Heim & Kratzer style analysis of a yet incomplete sentence with *subject* + *verb*:

  ![Tree diagram]

  - the princess
  - paints

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

- However, psycholinguistic studies show that *subject* + *verb* is composed immediately (e.g., Knoeferle et al. 2005)
Incremental Disambiguation Via Event Information

(1) Die Prinzessin malt offensichtlich...
The princess$_{nom./acc.}$ paints obviously...

Knöferle et al. (2005, Exp. 1), visual-world paradigm:

Participants are able to semantically interpret subject + transitive verb and revise the structure if it does not fit the context without a syntactic cue.

Here: An incremental compositional semantics proposed by Bott & Sternefeld (in press) based on continuation semantics (Barker 2002)

\[
\left[\begin{array}{c}
\text{the princess} \\
\text{paints} \\
\ldots
\end{array}\right] = \\
\lambda c_{\langle t, t \rangle} \lambda p_t [c(\exists e (\text{paints}(e) \wedge p \wedge \text{agent}(e, \text{the princess})))]
\]
Is Semantic Interpretation Incremental?

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

Different general cognitive conditions for syntactic and semantic interpretation?

- Working memory constraints enforce immediate structural integration (chunking)
- 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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Different general cognitive conditions for syntactic and semantic interpretation?

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- Is semantic interpretation, like syntactic processing, incremental throughout?
Are Quantifiers Interpreted Incrementally?

(2) Each$_{Q_1}$ [student]$_{R_1}$ [promised to [read]$_{S_2}$ at least one$_{Q_2}$ [paper]$_{R_2}$]$_{S_1}$

Three aspects of quantifier interpretation:

- Quantificational restriction (▷ $R_1$, $R_2$)
  - Reference to a contextually given set (e.g., Westerståhl 1985)
  - Is restriction computed incrementally (Kaan et al. 2006)?

(3) Eight flowers were put in a vase. Six had a broken stem.

- Nuclear scope (▷ $S_1$, $S_2$)
  - Second argument of quantifiers
  - Are quantifiers interpreted incrementally (e.g. Urbach & Kutas 2010)?

(4) Most/Few farmers grow crops/worms.

- Relative scope (▷ $S_2$ embedded in $S_1$, but not vice versa)
  - Is relative scope assigned incrementally (e.g., Filik et al. 2005)?

(5) Each boy climbed some tree. The tree/The trees...
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:

  (6) Jeden seiner Schüler\(j\) hat genau ein Lehrer \(t_j\) . . .
  Each of his pupils\(j\) AUX exactly one teacher\(subject\) \(t_j\) . . .
  ’Exactly one teacher AUX each of his pupils . . .’

- Scope interaction without scope reconstruction:

  (7) 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
- Our analysis can deal with many sorts of incomplete sentences
Variables $c$ and $p$ provide slots to fill in information yet to come.

**Composition** rule (cf. categorial grammar, e.g. Steedman 2001):

$$\Hsquare{\alpha > \beta} = \lambda c_{\langle t, t \rangle}[[\alpha][[\beta](c)]]$$
$$\Hsquare{\alpha < \beta} = \lambda c_{\langle t, t \rangle}[[\beta][[\alpha](c)]]$$

Lexical items:

- $\Hsquare{\text{exactly one teacher}_i} = \lambda c_{\langle t, t \rangle} \lambda p_t \exists x_i [\text{teacher}(x_i) \land c(p \land \text{agent}(e, x_i))]$  
- $\Hsquare{\text{each of his}_i \text{ pupils}_j} = \lambda c_{\langle t, t \rangle} \lambda p_t \forall x_j [(\text{pupil}(x_j) \land \text{of}(x_j, x_i)) \rightarrow c(p \land \text{patient}(x_j))]$  
- $\Hsquare{\text{not}} = \lambda c_{\langle t, t \rangle} \lambda p_t. \neg c(p)$
(1) Each of his pupils \(j\) has exactly one teacher \(t_j\) …

\[
\lambda c_{\langle t,t \rangle}[[\text{each of his pupils}_j][[\text{exactly one teacher}_i](c)]] =
\lambda c_{\langle t,t \rangle} \lambda p_t[\forall x_j(\text{pupil}(x_j) \land \text{of}(x_j, x_i)) \rightarrow
\exists! x_i.\text{teacher}(x_i) \land c(p \land \text{agent}(e, x_i) \land \text{patient}(e, x_j))]
\]

▶ Variable \(x_i\) unbound, scope inversion (reconstruction) is required

\[
\lambda c_{\langle t,t \rangle}[[\text{exactly one teacher}_i][[\text{each of his pupils}_j](c)]] =
\lambda c_{\langle t,t \rangle} \lambda p_t[\exists! x_i\text{teacher}(x_i) \land \forall x_j(\text{pupil}(x_j) \land \text{of}(x_j, x_i)) \rightarrow
\text{c}(p \land \text{patient}(e, x_j) \land \text{agent}(e, x_i))]
\]

Aoshima et al. (2009): Incremental binding in a head-final language (Japanese)
Each of his pupils has exactly one teacher . . .

\[
\lambda c_{\langle t,t \rangle} [[\text{each of his pupils}] [[\text{exactly one teacher}] (c)]] = \\
\lambda c_{\langle t,t \rangle} \lambda p_t [\forall x_j (\text{pupil}(x_j) \land \text{of}(x_j, x_i)) \rightarrow \\
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Aoshima et al. (2009): Incremental binding in a head-final language (Japanese)
(1) Jeden seiner Schüler hat genau ein Lehrer $t_j$ . . .
Each of his pupils has exactly one teacher $t_j$ . . .

\[ \lambda c_{\langle t,t \rangle}[[\text{each of his pupils}]][[\text{exactly one teacher}] (c)] = \lambda c_{\langle t,t \rangle} \lambda p_{\langle t \rangle} [\forall x_j(\text{pupil}(x_j) \land \text{of}(x_j, x_i)) \rightarrow \exists! x_i.\text{teacher}(x_i) \land c(p \land \text{agent}(e, x_i) \land \text{patient}(e, x_i))] \]

▶ Variable $x_i$ unbound, scope inversion (reconstruction) is required

\[ \lambda c_{\langle t,t \rangle}[[\text{exactly one teacher}]][[\text{each of his pupils}] (c)] = \lambda c_{\langle t,t \rangle} \lambda p_{\langle t \rangle} [\exists! x_i \text{teacher}(x_i) \land \forall x_j(\text{pupil}(x_j) \land \text{of}(x_j, x_i)) \rightarrow c(p \land \text{patient}(e, x_j) \land \text{agent}(e, x_i))] \]

Aoshima et al. (2009): Incremental binding in a head-final language (Japanese)
Bott & Sternefeld (to appear) – Derivations

(2) Jeder / Kein Lehrer hat nicht... 
Every / No teacher has not...

\[ \lambda c_{\langle t, t \rangle} [[\text{\textit{every teacher}}_i]] [[\text{\textit{not\}}(c)]] = \lambda c_{\langle t, t \rangle} \lambda p_t \forall x_i[\text{\textit{teacher}}(x_i) \rightarrow \neg c(p \land \text{\textit{agent}}(e, x_i))] \]

\[ \lambda c_{\langle t, t \rangle} [[\text{\textit{no teacher}}_i]] [[\text{\textit{not\}}(c)]] = \lambda c_{\langle t, t \rangle} \lambda p_t \neg \exists x_i[\text{\textit{teacher}}(x_i) \land \neg c(p \land \text{\textit{agent}}(e, x_i))] \]

▷ No teacher should be harder to process than every teacher due to double negation
Jeder / Kein Lehrer hat nicht... Every / No teacher\textsubscript{nom.} has not...

1. $\lambda c_{\langle t,t \rangle}[[\text{every teacher}_i]][[\text{not}]](c)] = \lambda c_{\langle t,t \rangle} \lambda p_t \forall x_i[\text{teacher}(x_i) \rightarrow \neg c(p \land \text{agent}(e, x_i))]$

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\begin{itemize}
  \item No teacher should be harder to process than every teacher due to double negation
\end{itemize}
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4. Conclusions
Reconstruction Without Syntactic Reanalysis

(1) Jeden seiner Schüler_{1} lobte_{2} genau ein Lehrer t_{1} t_{2}.
Each of his pupils_{object} 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, but not in the linear reading
• Therefore, the object quantifier has to undergo scope reconstruction
Immediate Reconstruction Of Quantifiers?

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

\[ \forall x : \text{pupil of}(x,y) \rightarrow \ldots \]

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

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

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

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

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

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

- Check variable binding
- Linear scope cannot be maintained, object quantifier has to undergo scope reconstruction (\(\therefore \exists! \forall\))
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

(2) 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:**
  - (linear scope)
  \[ \lambda Q_2 \cdot \lambda Q_1 \cdot Q_1 (\lambda y. Q_2 (\lambda x. P(x)(y))) \]
  - (inverse scope)
  \[ \lambda Q_2 \cdot \lambda Q_1 \cdot Q_2 (\lambda y. Q_1 (\lambda x. P(x)(y))) \]

As shown above continuation semantics can handle scope independently of the verb:

- Can handle scope independently of the verb:
  - (linear scope)
  \[ \lambda p. \exists! y \left[ \text{TEACHER}(y) \land \forall x \left[ \text{STUDENT}(x) \rightarrow p \right] \right] \]
  - (inverse scope)
  \[ \lambda p. \forall x \left[ \text{STUDENT}(x) \rightarrow \exists! y \left[ \text{TEACHER}(y) \land p \right] \right] \]
(2) Genau ein Lehrer wird jeden Schüler . . .
Exactly one teacher will every student . . .

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As shown above continuation semantics can handle scope indepently of the verb:

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

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.
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 \(Q-V-Q/\mathit{his}\); in \(Q-\mathit{Aux}-Q/\mathit{his}\), 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.
Assumption 1 – Offline Preferences

Each of these pupils was praised by exactly one teacher.

Is (2) really ambiguous?

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

**linear**) $\exists \forall \exists \forall X, \forall \exists X \checkmark$

**inverse**) $\exists \forall \exists \forall X \checkmark, \forall \exists \forall X$

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

(2') 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 (2) is in fact ambiguous as shown by smaller difference with disambiguated condition (2’)
- Strong preference for linear scope (Assumption 1)
Assumption 2 – Preference For Bound Interpretations

(3) Peter\textsubscript{i} ist Klassenlehrer der Klasse 5a. Bei der gestrigen Lehrerkonferenz wurde er sehr überrascht. Jeden seiner\textsubscript{i} Schüler lobte mindestens ein Lehrer voller Wohlwollen. Das hatte er nicht erwartet.

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?
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

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

![Bar chart showing the percentage of chosen paraphrases for different conditions.](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)]] \]

\( \triangleright \) 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]
1) Jeden seiner Schüler | lobte | genau ein Lehrer | voller | Wohlwollen.  

Each of his pupils \( DO \) was praised by exactly one teacher full of goodwill

2) Jeden dieser Schüler | lobte | genau ein Lehrer | voller | Wohlwollen.  

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.

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.

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$_{DO}$ was praised by the new teacher full of goodwill

6) Jeden dieser Schüler | lobte | der neue Lehrer | voller | Wohlwollen.       
Each of these pupils$_{DO}$ was praised by the new teacher$_{Subj.}$ full of goodwill

7) Jeden seiner Schüler | hat | der neue Lehrer | voller | Wohlwollen | gelobt.             
Each of his pupils$_{DO}$ was by the new teacher$_{Subj.}$ full of goodwill praised

8) Jeden dieser Schüler | hat | der neue Lehrer | voller | Wohlwollen | gelobt.             
Each of these pupils$_{DO}$ was by the new teacher$_{Subj.}$ full of goodwill praised
Design And Methods

- 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

- 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 (*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.

- Early and late effects are not significantly correlated.
Discussion

Early effect:

- Failed search for a binder

Late effect:

- Interaction $DP \text{ type}^* \text{pronoun}$: 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:

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Do Our Findings Generalize 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
Entailment relations licensed by quantifiers – Monotonicity

(1) At least one boy wore a red t-shirt
    \[\Rightarrow\] At least one boy wore a t-shirt
    \[\not\Rightarrow\] At least one boy wore a red old t-shirt

(2) At most one boy wore a red t-shirt
    \[\not\Rightarrow\] At most one boy wore a t-shirt
    \[\Rightarrow\] At most one boy wore a red old t-shirt

- \([\text{red old t-shirt}] \subseteq [\text{red t-shirt}] \subseteq [\text{t-shirt}]\)
- Monotone increasing quantifiers (e.g. at least one) license inferences from subsets to supersets
- Monotone decreasing quantifiers (e.g. at most one) license inferences from supersets to subsets
- Monotone decreasing Qs are harder than increasing Qs (e.g. Urbach et al. 2010; Deschamps et al. 2015)
Entailment relations licensed by quantifiers – Monotonicity

(1) At least one boy wore a red t-shirt
   $\implies$ At least one boy wore a t-shirt
   $\iff$ At least one boy wore a red old t-shirt

(2) At most one boy wore a red t-shirt
   $\iff$ At most one boy wore a t-shirt
   $\implies$ At most one boy wore a red old t-shirt

- $[\text{red old t-shirt}] \subseteq [\text{red t-shirt}] \subseteq [\text{t-shirt}]$
- *Monotone increasing* quantifiers (e.g. *at least one*) license inferences from subsets to supersets
- *Monotone decreasing* quantifiers (e.g. *at most one*) license inferences from supersets to subsets
- Monotone decreasing Qs are harder than increasing Qs (e.g. Urbach et al. 2010; Deschamps et al. 2015)
Candidate Manipulation: Monotonicity

- Monotonicity intuitively produces over-additive effects:
  1. At least one boy tickled more than two girls.
  2. At most one boy tickled more than two girls.
  3. At least one boy tickled fewer than three girls.
  4. At most one boy tickled fewer than three girls.

However, (3-d) may be so complex that composition does not succeed (cf. Bott et al. 2013; Bott et al., under review)

Somewhat simpler combination: quantifier and negation

- More than half of the kids did not eat a burger.
- Less than half of the kids did not eat a burger.
Pilot Study: Establishing Over-Additive Effects

- In an eyetracking experiment, 48 participants read 32 German sentences such as

\[(5)\] Auf \(Q\) Kreuze trifft zu, dass sie (\textit{nicht}) blau sind.  
On \(Q\) crosses holds that they (\textit{not}) blue are.  
’\(Q\) crosses are such that they are (\textit{not}) blue.’

- \(2 \times 2\) within design – \textit{montonicity} \times \textit{negation}

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

- Negation in clause-bounded position to guarantee linear interpretation

- After reading, participants performed sentence-picture verification
Main result: *Direction of entailment* and *negation* affect reading times over-additively (interaction: $t = 2.78$)

Manipulation well-suited as marker of semantic composition to test *INCREMENTAL SCOPE INTERPRETATION* in sentences with linear scope
Pretest: Only linear scope interpretations

- Rise-fall intonation might trigger scope reconstruction (e.g. Büring 1997)
- Truth-value judgment + read aloud task

(6) More/Less than half of the kids did not eat a burger.

| Kid 1: ✓ | Kid 5: ✓ |
| Kid 2: ✓ | Kid 6: X |
| Kid 3: X | Kid 7: X |
| Kid 4: X | Kid 8: ✓ |

\[ Q \rightarrow X \quad \neg Q \checkmark \]

- 20 participants
- Both conditions received \( \approx 100\% \) no-responses (\( \triangleright \) linear scope)
- Analysis of the recorded productions: not a single rise-fall (hat) contour
Pretest: Only linear scope interpretations

- Rise-fall intonation might trigger scope reconstruction (e.g. Büring 1997)
- Truth-value judgment + read aloud task

(6) More/Less than half of the kids did not eat a burger.

<table>
<thead>
<tr>
<th>Kid 1: ✓</th>
<th>Kid 5: ✓</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kid 2: ✓</td>
<td>Kid 6: X</td>
</tr>
<tr>
<td>Kid 3: X</td>
<td>Kid 7: X</td>
</tr>
<tr>
<td>Kid 4: X</td>
<td>Kid 8: ✓</td>
</tr>
</tbody>
</table>

Q¬ X ¬Q ✓

- 20 participants
- Both conditions received ≈100% no-responses (linear scope)
- Analysis of the recorded productions: not a single rise-fall (hat) contour
Experimental Design

(1/2) Mehr | als | die Hälfte | der Kollegen | studierten (nicht) | in den USA | …
More than half of the colleagues studied (not) in the USA.
‘Less than half of the colleagues did (not) study in the USA.’

(3/4) 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.’

(5/6) Mehr | als | die Hälfte | der Kollegen | haben (nicht) | in den USA | studiert …
More than half of the colleagues have (not) in the USA studied.
‘Less than half of the colleagues did (not) study in the USA.’

(7/8) 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.’

- $2 \times 2 \times 2$ within design – verb position $\times$ monotonicity $\times$ negation
Hypotheses and Predictions

**Strictly Incremental Interpretation**
- Irrespective of *verb position*, composition takes place immediately
  - Immediate processing cost of *monotonicity* and *negation*
  - Two-way but no three-way interaction.

**Verb Dependent Incrementality**
- Composition delayed until main verb is encountered
  - Three-way interaction: *verb position* $\times$ *monotonicity* $\times$ *negation*

**Global Interpretation**
- Composition delayed until the end of the sentence
Methods

- 32 native German participants
- Same procedure as in the reconstruction study
- 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 + 160 fillers
- 40 trials followed by diagram judgment task, 60 trials followed by comprehension questions
- 8 lists in a latin square design
Results – No early composition effects

Effects at the verb+negation region (+/- 1 se):

First-pass times:

First-pass regression ratios:

- No significant 2- or 3-way interactions involving *monotonicity* and *negation*
- At following regions also no interaction(s)
Composition effect at sentence-final region...

Regression-path durations of the sentence final region (+/- 1 se):

- Only after having read the entire sentence, participants start to show a monotonicity effect (main effect (ANOVAs): $p_1 < .01$; $p_2 = .06$)
... due to re-reading of the verb+negation ROI

Rereading effects at the verb+negation region (+/- 1 se):

Second pass times:

![Graph showing second pass times for different conditions.]

Proportions of *regressions in*:

![Graph showing proportions of regressions for different conditions.]

- Significant 2-way interaction *monotonicity × negation* ($p_{1/2} < .05$):
  - Negation affected second pass times for *less than*, in particular
  - Same finding for *regressions in*

Bott (N & Q, Wroclaw)  Delayed effects of quantifier scope  August 30th, 2016  56 / 66
Discussion

Further evidence for **GLOBAL INTERPRETATION**

- Clear indication of enhanced processing complexity in the two *less than ... negation* conditions
- Scope effects delayed until the end of the sentence
- Relative scope was assigned globally even though no scope inversion was required
Late effects due to pragmatic constraints on negative statements?

(7) In front of the castle there is no ghost.

- Negative statements are often interpreted in a delayed manner (e.g. Kaup et al. 2006)
- Tian & Breheny (2010): Pragmatic effect, negative statements require special contextual licensing (⊿ accommodation of the appropriate question under discussion (QU))

(8) A: Could you please tell me something about the buildings in this street?
    B: This is a museum.
    B: #This is not a museum.

(9) A: Is this a museum?
    B: (No), this is not a museum.
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(7) In front of the castle there is no ghost.

- Negative statements are often interpreted in a delayed manner (e.g. Kaup et al. 2006)
- Tian & Breheny (2010): Pragmatic effect, negative statements require special contextual licensing (⊿ accommodation of the appropriate question under discussion (QUD))

(8) A: Could you please tell me something about the buildings in this street?
   B: This is a museum.
   B: #This is not a museum.

(9) A: Is this a museum?
   B: (No), this is not a museum.
Tian et al. (2016)

Eyetracking study in the visual world paradigm:

(10) a. Matt has shut the window.  
    b. Matt has not shut the window. 
    c. It is Matt who has shut the window. 
    d. It is Matt who has not shut the window.
An alternative pragmatic explanation

(11) a. QUD: How many students ate in the cafeteria?
   Q students ate in the cafeteria.

   b. QUD: How many students did not eat in the cafeteria?
   Q students did not eat in the cafeteria.

- QUD can only be determined at the end of the sentence
- Too much indeterminacy:
  - Information structure
  - Scope
  - Event information
- Wait and see strategy
Cleft sentences

(12) It’s more / less than half of the colleagues that have not . . .

- Information structure obvious right from the start
- Sentence structure disambiguates towards linear scope
- Incremental construction of QUD:
  - For a predicate P yet to come: **How many of the colleagues have P-ed?**
- Do we find incremental effects if we turn items into clefts?
- Still no concrete event information available!
Running Eyetracking Experiment

- Same methods as in the previous study
- 22 participants so far
- No clear composition effects yet
Overview

1. Introduction – Incrementality in Semantic Interpretation

2. Scope Reconstruction (Bott & Schlotterbeck, 2015)
   - Pretests
   - Scope Inversion Effects during Online Comprehension

3. Scope Interaction without Reconstruction
   - Effects of Quantificational Complexity in Linear Readings
   - Future Steps: Cleft Sentences and Context Effects

4. Conclusions
Conclusions

- Two studies on the relative time course of scope interpretation
  - Scope reconstruction due to bound variable interpretation
  - Effects of quantificational complexity during the online interpretation of linear scope
- Both studies provided evidence for global interpretation of quantifier scope
- Future work: Can pragmatic factors aid incremental interpretation?
  - QUD construction guided by information structure in clefts?
  - Early effects due to discourse context?

This hotel has a restaurant that offers dinner. Some guests like to eat in the restaurant, but others prefer to go out. Yesterday evening it were less than half of the guests that didn’t . . .
Where this might take us . . .

This hotel has a restaurant that offers dinner. Some guests like to eat in the restaurant, but others prefer to go out. *Yesterday evening it were less than half of the guests that didn’t . . .*

- If we find incremental effects in these examples (in opposition to sentences in isolation) scope interpretation would be a two-step process
  - Step 1: Compute an underspecified representation containing all the event information
  - Step 2: Specify scope relations

- Proposal related to the scenario-mapping and focus theory by Sanford & Garrod (1998)

- Related back to reading sentences with multiple scope operators:
  - First-pass reading: Establish a scenario underspecified for scope
  - Rereading: Compute scope interpretation
Thank you very much for your attention!

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