Processing bound variable interpretations under inverse scope

Oliver Bott & Fabian Schlotterbeck
Project B1, Collaborative Research Centre 833

Workshop:
Variables at the interface between form and meaning

July 12th, 2012
Overview

1 Introduction

2 Pretests – Justifying the Implicit Assumptions
   - Pretest 1
   - Pretest 2
   - Pretest 3

3 Scope Inversion Effects during Online Comprehension
   - Eyetracking during reading
The semantic representation is 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.
Psycholinguists assume incremental interpretation

(1) Pick up the tall...
Challenges for incremental interpretation

(1) Pick up the tall glass / pitcher

- Continuing (1) with *pitcher* causes difficulty
- Immediate interpretation may require reinterpretation

(2) Einer der Tische hat alle Wände in diesem Saal berührt
One of the tables has all walls in this hall touched

- At first, (2) reads implausible
- Is this due to immediate (linear) scope assignment that has to be given up once the verb is encountered?
- In contrast to (1), abstract relation between sets
Challenges for incremental interpretation

(1) Pick up the \textit{tall glass/pitcher}

- Continuing (1) with \textit{pitcher} causes difficulty
- Immediate interpretation may require reinitialization

(2) Einer der Tische hat \textit{alle Wände} in diesem Saal \textit{berührt}

- At first, (2) reads implausible
- Is this due to immediate (linear) scope assignment that has to be given up once the verb is encountered?
- In contrast to (1), abstract relation between sets
Challenges for incremental interpretation

(1) Pick up the tall glass / pitcher

- Continuing (1) with *pitcher* causes difficulty
- Immediate interpretation may require reinterpretation

(2) Einer der Tische hat alle Wände in diesem Saal berührt

One of the tables has all walls in this hall touched

- At first, (2) reads implausible
- Is this due to immediate (linear) scope assignment that has to be given up once the verb is encountered?
- In contrast to (1), abstract relation between sets
Challenges for incremental interpretation

(1) Pick up the tall glass / pitcher

- Continuing (1) with *pitcher* causes difficulty
- Immediate interpretation may require reinterpretation

(2) Einer der Tische hat alle Wände in diesem Saal berührt
One of the tables has all walls in this hall touched

- At first, (2) reads implausible
  - Is this due to immediate (linear) scope assignment that has to be given up once the verb is encountered?
   - In contrast to (1), abstract relation between sets
Challenges for incremental interpretation

(1) Pick up the tall glass / pitcher
- Continuing (1) with pitcher causes difficulty
  - Immediate interpretation may require reinterpretation

(2) Einer der Tische hat alle Wände in diesem Saal berührt
  One of the tables has all walls in this hall touched
- At first, (2) reads implausible
- Is this due to immediate (linear) scope assignment that has to be given up once the verb is encountered?
  - In contrast to (1), abstract relation between sets
Challenges for incremental interpretation

(1) Pick up the tall glass / pitcher

- Continuing (1) with pitcher causes difficulty
- Immediate interpretation may require reinterpretation

(2) Einer der Tische hat alle Wände in diesem Saal berührt
One of the tables has all walls in this hall touched

- At first, (2) reads implausible
- Is this due to immediate (linear) scope assignment that has to be given up once the verb is encountered?
- In contrast to (1), abstract relation between sets
Previous online studies on quantifier interaction

have almost entirely used singular/plural continuations (cf. Kurtzman & MacDonald 1993)

(3) Every kid climbed a tree. The tree was/The trees were full of apples.

Inappropriate to test incremental scope assignment:

‘Disambiguation’ appears only in the subsequent sentence

(4) Each kid is such that it climbed exactly one tree. This tree was full of apples.

We therefore decided to use a different disambiguation: scope inversion due to variable binding
Previous online studies on quantifier interaction

have almost entirely used singular/plural continuations (cf. Kurtzman & MacDonald 1993)

(3) Every kid climbed a tree. The tree was/The trees were full of apples.

Inappropriate to test incremental scope assignment:

- ‘Disambiguation’ appears only in the subsequent sentence

(4) Each kid is such that it climbed exactly one tree. This tree was full of apples.

We therefore decided to use a different disambiguation: scope inversion due to variable binding
Previous online studies on quantifier interaction

have almost entirely used singular/plural continuations (cf. Kurtzman & MacDonald 1993)

(3) Every kid climbed a tree. The tree was/The trees were full of apples.

Inappropriate to test incremental scope assignment:
- ‘Disambiguation’ appears only in the subsequent sentence

(4) Each kid is such that it climbed exactly one tree. This tree was full of apples.

We therefore decided to use a different disambiguation: scope inversion due to variable binding
Previous online studies on quantifier interaction

have almost entirely used singular/plural continuations (cf. Kurtzman & MacDonald 1993)

(3) Every kid climbed a tree. The tree was/The trees were full of apples.

Inappropriate to test incremental scope assignment:

- ‘Disambiguation’ appears only in the subsequent sentence

(4) Each kid is such that it climbed exactly one tree. This tree was full of apples.

We therefore decided to use a different disambiguation:

Scope inversion due to variable binding
Previous online studies on quantifier interaction have almost entirely used singular/plural continuations (cf. Kurtzman & MacDonald 1993)

(3) Every kid climbed a tree. The tree was/The trees were full of apples.

Inappropriate to test incremental scope assignment:

- ‘Disambiguation’ appears only in the subsequent sentence

(4) Each kid is such that it climbed exactly one tree. This tree was full of apples.

▷ We therefore decided to use a different disambiguation: scope inversion due to variable binding

Bott & Schlotterbeck scope inversion
Immediate interpretation of a doubly quantified sentence

(5) Jeden seiner Schüler ...
Each of his pupils$_{Direct Object}$ ...

$\forall x : pupil of(x, y) \rightarrow \ldots$

- Something happens to each of y’s pupils
Immediate interpretation of a doubly quantified sentence

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

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

- Apply quantifier hierarchy to compute rel. weight of QPs
- Linear scope \( \forall \exists! \) is preferred
Immediate interpretation of a doubly quantified sentence

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

\exists! z : teacher(z) \land \forall x : pupil.of(x, z) \to \ldots

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

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

In sentences like (5) we can test whether readers assign 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

(6) 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:**
  - \( \lambda Q_2 . \lambda Q_1 . Q_1 (\lambda y . Q_2 (\lambda x . P (x) (y))) \) (subj. wide scope)
  - \( \lambda Q_2 . \lambda Q_1 . Q_2 (\lambda y . Q_1 (\lambda x . P (x) (y))) \) (obj. wide scope)

Barker (2002)’s continuation semantics:

- **Can handle scope independently of the verb:**
  - \( \lambda p . \exists ! y [\text{TEACHER}(y) \land \forall x [\text{STUDENT}(x) \land p]] \) (subj. wide scope)
  - \( \lambda p . \forall x [\text{STUDENT}(x) \rightarrow \exists ! y [\text{TEACHER}(y) \land p]] \) (obj. wide scope)
Is the verbal predicate required?  
Hendriks 1993 vs. Barker 2002

(6) 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:
  \( \lambda Q_2 \cdot \lambda Q_1 \cdot Q_1 (\lambda y. Q_2 (\lambda x. P (x) (y))) \) (subj. wide scope)
  \( \lambda Q_2 \cdot \lambda Q_1 \cdot Q_2 (\lambda y. Q_1 (\lambda x. P (x) (y))) \) (obj. wide scope)

Barker (2002)’s continuation semantics:
- Can handle scope independently of the verb:
  \( \lambda p. \exists! y [\text{TEACHER}(y) \land \forall x [\text{STUDENT}(x) \land p]] \) (subj. wide scope)
  \( \lambda p. \forall x [\text{STUDENT}(x) \rightarrow \exists! y [\text{TEACHER}(y) \land p]] \) (obj. wide scope)
The complete picture

Incremental scope assignment:

- Verb independent: quantifiers immediately take relative scope independently of the verb.
- Verb dependent: relative scope is computed as soon as the quantifiers and the verbal predicate have been encountered.

Late interpretation:

Relative scope is only computed at the boundary of the sentence the quantifiers appear in.
Introduction
Pretests
Scope Inversion Effects during Online Comprehension

Design of the study –
Measure inversion-costs due to variable binding

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

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

9) 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.

10) 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 Computation 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.
Overview

1 Introduction

2 Pretests – Justifying the Implicit Assumptions
   - Pretest 1
   - Pretest 2
   - Pretest 3

3 Scope Inversion Effects during Online Comprehension
   - Eyetracking during reading
Pretest 1 – Offline preferences

(11) Jeden dieser Schüler\textsubscript{i} lobte\textsubscript{j} genau ein Lehrer \textsubscript{t\textsubscript{i} t\textsubscript{j}}.

Each of these pupils\textsubscript{DO} was praised by exactly one teacher\textsubscript{Subj}.

(12) Genau einen Schüler\textsubscript{i} lobte\textsubscript{j} jeder Lehrer \textsubscript{t\textsubscript{i} t\textsubscript{j}}.

Exactly one pupil\textsubscript{DO} was praised by each teacher\textsubscript{Subj}.

- Is (11) really ambiguous? Is there a preference for linear scope?
- What about the alternative constellation of quantifiers in (12)?
- Aim: choose the optimal configuration of quantifiers
(11) Jeden dieser Schüler lobte genau ein Lehrer voller Wohlwollen.

Each of these pupils was praised by exactly one teacher full of goodwill.
Design and methods

- For both pairings of quantifiers we included unambiguous controls:
  
  (12) Für jeden dieser Schüler gilt: ihn lobte genau ein Lehrer.  
       *For each of these pupils holds: him praised exactly one teacher.*

  (13) Für genau einen Schüler gilt: ihn lobte jeder Lehrer.

- Within design: 2 quantifiers (*∀* first vs. *∃!* first) x 2 ambiguity (*ambiguous* vs. *unambiguous*) x 2 diagram (*∃!*∀ vs. *∀∃!*)

- 36 items + 61 fillers (15 false)
- Acceptability judgments (7 point scale)
- 48 participants
- Latin square design
Each > exactly one is ambiguous

- Linear scope preferred over inverse scope

Exactly one > each wouldn’t meet our requirements!
Pretest 1 – Results

- Each > exactly one is ambiguous
  - Linear scope preferred over inverse scope
- Exactly one > each wouldn’t meet our requirements!
Pretest 2 – Bound variable interpretations?
(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
- Will readers in our experiments interpret the possessive pronoun anaphorically?
Interpreting the possessive anaphorically


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*
- *Will readers in our experiments interpret the possessive pronoun anaphorically?*
Pretest 2a – A paraphrase selection task

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

(Int. 1) Bound variable
(Int. 2) Sentence external coreferential int. with linear scope
(Int. 3) Sentence external coreferential int. with inverse scope

**Task:**
Choose among the set of three paraphrases
Pretest 2b – Is variable binding under inverse scope a last resort?

(QQ/his) Jeden seiner Schüler lobte genau ein Lehrer, sagte Fritz
Each of his pupils was praised by exactly one teacher, said Fritz

(Int. 1) Bound variable

(Int. 2) Coreferential int. \((\text{his}_i = \text{Fritz'}_i)\) with linear scope

(Int. 3) Coreferential int. \((\text{his}_i = \text{Fritz'}_i)\) with inverse scope

Baseline control:

(contr.) Jeden ihrer Schüler lobte genau eine Lehrerin, sagte Fritz
Each of her pupils was praised by exactly one fem. teacher, said Fritz
Pretest 2b – Is variable binding under inverse scope a last resort?

(QQ/his) Jeden seiner Schüler lobte genau ein Lehrer, sagte Fritz
Each of his pupils was praised by exactly one teacher, said Fritz

(Int. 1) Bound variable

(Int. 2) Coreferential int. ($his_i = Fritz’_i$) with linear scope

(Int. 3) Coreferential int. ($his_i = Fritz’_i$) with inverse scope

Baseline control:

(contr.) Jeden ihrer Schüler lobte genau eine Lehrerin, sagte Fritz
Each of her pupils was praised by exactly one fem. teacher, said Fritz
Pretest 2 – Design and methods

Pretest 2a:
- Within design: 2 pronoun (QQ/his vs. QQ/these) x 2 verb position (Q-V-Q vs. Q-Aux-Q)

Pretest 2b (‘QQ, said Fritz’):
- Within design: 2 gender (match vs. mismatch) x 2 verb position (Q-V-Q vs. Q-Aux-Q)

Methods:
- 48 participants
- 32 items in eight conditions + 48 fillers
- always three paraphrases (+ none fits button)
- In [QQ/these] and [QQ/mismatch] dummy paraphrase instead of bound paraphrase
- 8 lists in a latin square design
Pretest 2 – Results

- *his*: pref. for linear int.
- + *his*: bound variable int.
- + *his*: scope inversion!
Introduction

Pretests

Scope Inversion Effects during Online Comprehension

Pretest 2 – Results

- *his*: pref. for linear int.
- + *his*: bound variable int.
- + *his*: scope inversion!

Bound interpretation even if referent is expl. provided
Pretest 3 – Inherent complexity of [QQ/+his] vs. [QQ/–his] (independently of scope inversion)
The readings reconsidered

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]

Introduction
Pretests
Scope Inversion Effects during Online Comprehension
Pretest 1
Pretest 2
Pretest 3

Bott & Schlotterbeck

scope inversion
The readings reconsidered

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]
Pretest 3 – Reading times of QQ-his vs. QQ-these sentences with reversed order of quantifiers

QQ/+his  Genau ein Lehrer | lobte | jeden seiner Schüler | voller | Wohlwollen.

Exactly one teacher | praised | each of his pupils | full of | goodwill.

QQ/–his  Genau ein Lehrer | lobte | jeden dieser Schüler | voller | Wohlwollen.

Exactly one teacher | praised | each of these pupils | full of | goodwill.

- 16 participants
- Self-paced reading with sensicality judgment ratings
- 32 items in 2 conditions + 96 fillers
- 2 lists in a latin square design
Pretest 3 – Results and discussion

- Both conditions were read equally fast
- No differences in sensicality judgments or judgment RTs

Once the LF of the bound inverse reading is computed, difficulty is the same as in \([QQ/–his]\)
Both conditions were read equally fast
- No differences in sensicality judgments or judgment RTs
- Once the LF of the bound inverse reading is computed, difficulty is the same as in [QQ/–his]
Overview

1. Introduction

2. Pretests – Justifying the Implicit Assumptions
   - Pretest 1
   - Pretest 2
   - Pretest 3

3. Scope Inversion Effects during Online Comprehension
   - Eyetracking during reading
Eyetracking study – Doubly quantified sentences

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

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

4) Jeden dieser Schüler | hat | genau ein Lehrer | voller | Wohlwollen | gelobt. [Q-Aux-Q/–his]
   Each of these pupils<sub>DO</sub> was by exactly one teacher<sub>Subj.</sub> full of goodwill praised
Eyetracking study – QDef controls

5) Jeden seiner Schüler | lobte | der neue Lehrer | voller | Wohlwollen. [Q-V-Def/+his]
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. [Q-V-Def/–his]
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. [Q-Aux-Def/+his]
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. [Q-Aux-Def/–his]
Each of these pupils\textsubscript{DO} was by the new teacher\textsubscript{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
- 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
Eye-movements during reading

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*\(^{\ast}\) *pronoun* interaction) at 2nd QP
  - Incremental scope assignment?
Proportions of regressions out

- **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
Proportions of regressions out

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 the start of scope revision?

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 $DP\ type^* pronoun$: Scope inversion
- Main effect of $DP\ type$: Constructing a model for a QQ sentence may be more difficult than constructing a model for a QDef sentence

Late interpretation:
Inverse scope is only computed at the boundary of the sentence the quantifiers appear in.
Thank you very much for your attention!