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Continuations in Type Logical Grammar

Grafting Trees:
Computational Linguistics
What a linguist cares about

Entailment

Truth conditions are part of sentence meanings.

\[ \text{Somebody liked a computer science course} \quad \vdash \quad \text{Any course} \]

\[ \text{Nobody liked any course} \quad \not\vdash \quad \text{Any course} \]

Nobody liked any course
What a linguist cares about

Entailment

Ambiguity

Truth conditions are part of sentence meanings.

Nobody liked any course
Nobody liked a course
Somebody liked a computer science course
Somebody liked any computer science course
What a linguist cares about

Entailment

Truth conditions are part of sentence meanings.

Ambiguity

Acceptability

—Abraham Lincoln

You can fool some of the people all of the time, and all of the people some of the time, but you can not fool all of the people all of the time.

“inverse scope”

“linear scope”

Truth conditions are part of sentence meanings.
This talk deals with English, but the approach hopefully extends to other languages.

What a linguist cares about

Entailment

Nobody liked any course

Few students liked any course

Every student liked any course

Any student liked no course

Truth conditions are part of sentence meanings.

Ambiguity

Acceptability

“inversescope”

“linearscope”

You can fool some of the people all of the time, but you cannot fool all of the people all of the time.”

— Abraham Lincoln
The Curry-Howard isomorphism

- **Syntax**: Deduction rules for proving grammaticality
- **Semantics**: Translation to a logical metalanguage
- **Acceptability**: Entailment
Delimited continuations for quantification

Unary modalities for polarity sensitivity

Evaluation order for linear precedence

Staging for scope ambiguities

Payoffs

For linguistics:

Cover more empirical data.

Relate (denotational) semantics to (operational) psycholinguistics?

For computer science:

Understand delimited continuations geometrically and logically.

Staging side effects?

Outline

Somebody liked everybody’s mother.

Anybody liked nobody’s mother.

Nobody liked anybody’s mother.

* Alice liked anybody’s mother.

Alice liked everybody’s mother.

Alice liked Bob.

NEW

NEW

OLD

NEW

OLD
A sequent is complete iff its antecedent is built up using the connective only and its conclusion is a „sentence“.

Alice liked Bob.

\[ \begin{array}{c}
  Alice \circ (\text{liked} \circ \text{Bob}) \\
  \text{s} \downarrow \text{du} \rightarrow \\
  \text{liked} \circ \text{Bob} \\
  \text{du} \rightarrow \\
  \text{Alice} \rightarrow
\end{array} \]

\[ \begin{array}{c}
  du \rightarrow \\
  \text{Bob} \\
  du/(s\downarrow du) \rightarrow \\
  \text{liked} \circ \text{Bob}
\end{array} \]

Alice liked Bob.
**Implications**

(non-commutative; non-associative)

B \circ C means „B followed by C”

**Tensor**

**Axiom**

\[ A \rightarrow A \]

\[ \{ \wedge \} L \rightarrow A \]

\[ L \circ B \rightarrow A \]

\[ L \circ C \rightarrow A \]

**Natural deduction rules for categorial grammar** (a kind of type logical grammar)

A sequent is complete iff its antecedent is built up using the \( \circ \) connective only and its conclusion is s („sentence“).

\[ A \rightarrow A \]

\[ A \rightarrow \{ \wedge \} A \]

\[ A \rightarrow L \circ B \]

\[ A \rightarrow L \circ C \]

\[ A \rightarrow s \]

\[ A \rightarrow du \]

**Linear Logic for Linguistics**
Everybody liked Bob.
Somebody liked Bob.
Nobody liked Bob.

\[ \text{nobody} \left( \text{liked} Bob \right) \]
\[ \text{nobody} \left( \text{liked} Bob \right) \]
\[ \text{nobody} \left( \text{liked} Bob \right) \]

In-situ quantification
In-situ quantification


\[ \text{\textcopyright Alice's mother liked Bob.} \]

\[ \text{\textcopyright Nobody liked \textcopyright Alice's mother.} \]

\[ \text{\textcopyright Nobody liked Bob.} \]

\[ \text{\textcopyright Somebody liked Bob.} \]

\[ \text{\textcopyright Everybody liked Bob.} \]
Delimited continuations

\[
\text{Alice} \xrightarrow{\text{liked}} \text{ nobody}'s mother} \xrightarrow{\text{I}}
\]

\[
\text{nobody} \xrightarrow{\text{Alice}} \text{my sister}
\]

\[
\text{nobody} \xrightarrow{\text{Alice}} \text{my sister} \xrightarrow{\text{I}}
\]
Delimited continuations

\[ (\text{liked} \Diamond \text{mother} \circ (\text{nobody} \circ \text{liked})) \triangleleft (\text{liked} \circ \text{mother} \circ \text{nobody}) \]
(s\text{du})/s \rightarrow \text{ nobody} \rightarrow \text{ nobody}\text{'smother}\

\text{ Alice} \\text{ liked} (\text{ nobody}'\text{smother})\

\text{ I liked } \text{ Alice} \text{'s mother}\

\text{ Nobody} \rightarrow \text{ nobody} \rightarrow \text{ nobody}'}\text{smother}\

\text{ Alice} \text{'s mother} \rightarrow (\text{ I liked } \text{ Alice} \rightarrow (\text{ nobody } \circ \text{ somebody }) \circ \text{ I liked})\

\text{ Delimited continuations}
Delimited continuations: structural postulates
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Delimited continuations: structural postulates
Alice (liked (nobody's mother))

Left
\[ S \vdash \{ (\text{nobody} \triangleleft (\text{Alice} \triangleleft 1)) \circ (\text{nobody} \circ \text{nobody} \circ \text{mother}) \} \]

Right
\[ S \vdash \{ (\text{Alice} \triangleleft 1) \circ ((\text{nobody} \circ \text{nobody} \circ \text{mother}) \circ \text{i like}) \} \]

Right
\[ S \vdash \{ 1 \circ ((\text{nobody} \circ \text{mother}) \circ \text{i like}) \} \]

Root
\[ S \vdash \{ ((\text{Alice} \circ \text{mother} \circ \text{nobody}) \circ \text{i like}) \} \]

Delimited continuations: structural postulates
Delimited continuations: structural postulates
Ambiguity in delimitation: “Alice told Bob to criticize nobody’s mother.”

Delimited continuations for in-situ quantification
The quantifier evaluated earlier takes wider scope in the syntactic proof and the
truth-conditional meaning.

\[ \text{Delimited continuations for in-situ quantifications} \]
Meaning affects ambiguity and acceptability, but order matters too.

Very roughly, if it is allergic to negative contexts:

- "Some" is a positive polarity item:
  - "Any" is a negative polarity item:
    - *Any* student liked no course.
    - *No* student liked a course.
    - *No* student liked some course.
    - *No* student liked an any course.
    - *No* student liked an any course.

But do not behave the same:

\[ x \ni \text{student}(x) \lor \text{called}(x) \]

\[ \text{Did any student call?} \]

\[ \text{Did some student call?} \]

\[ \text{Did a student call?} \]

The quantifiers "a", "some", and "any" all look existential:

\[ \exists x \ni \text{called}(x) \]
Unary polarities

Denethreetypesforsentencesofvaryingpolarity:

\[ s = h r i (\text{verbsnowreturnthistype}) \]

\[ s + = h r i [\bar{p}] \]

\[ s - = [\bar{p}] h r i \]

Unary type constructors like \( h r i \) and \([\bar{p}]\) come in pairs. Each pair is an adjunction.

\[ \forall \langle d \rangle [\bar{d}] \rightarrow \forall \langle d \rangle \]

\[ \forall [\bar{d}] \rightarrow \forall \langle d \rangle \]

\[ \exists [\bar{d}] \rightarrow \exists \langle d \rangle \]

A handy Lemma:

\[ \text{Possibility} \]

\[ \text{Necessity} \]

Additional natural-deduction rules for unary connectives (focus on polarity

Unary type constructors like \( \langle d \rangle \) and \([\bar{d}]\) come in pairs. Each pair is an adjunction.

\[ s \langle \bar{d} \rangle [\bar{d}] = \_ s \]

\[ s \langle d \rangle [\bar{d}] \langle \bar{d} \rangle = + s \]

\[ s \langle \bar{d} \rangle = \circ s \]

Define three types for sentences of varying polarity:
Unary modalities for polarity sensitivity, cont'd

Nobody said that Alice liked anybody's mother.

Alice liked anybody's mother.

Anybody's mother |

\[ E \]

\[ s \rightarrow (s \text{ mother } \circ \text{ liked } (\text{Alice } \circ \text{ liked } _1)) \circ du \]

Root, Right, Right, Left:

\[ I[d] \]

\[ s \rightarrow ((s \text{ mother } \circ du) \circ \text{ liked } (\text{Alice } \circ \text{ liked } _1)) \langle d \rangle \]

\[ I\langle d \rangle \]

\[ s \rightarrow ((s \text{ mother } \circ du) \circ \text{ liked } (\text{Alice } \circ \text{ liked } _1)) \circ du \]

It's conclusion is of the form \( \langle \text{A} \rangle (\text{that is, either } s^0 \text{ or } s^+). \)

A sequent is complete iff its antecedent is built up using the \( \circ \) connective only and

Unary modalities for polarity sensitivity, cont'd
Unary modalities for polarity sensitivities

Prediction: the quantifiers in a sentence must form a valid transition sequence, from widest to narrowest scope.

(ambiguous) (unambiguous)
(\neg E \iff\neg E\ \text{unambiguous})

Any student liked no course.
A student liked no course.

\text{A student liked no course.}
\text{Some student liked no course.} \quad \text{No student liked a course.}
\text{No student liked some course.}

\begin{align*}
\frac{}{\circ s \leftarrow s} & \quad \frac{s}{\text{a woman}} \\
\frac{}{\circ s \leftarrow s} & \quad \frac{s}{\text{somebody}} \\
\frac{}{\circ s \leftarrow s} & \quad \frac{s}{\text{anybody}} \\
\frac{}{\circ s \leftarrow s} & \quad \frac{s}{\text{nobody}} \\
\frac{}{\circ s \leftarrow s} & \quad \frac{s}{\text{any}} \\
\frac{}{\circ s \leftarrow s} & \quad \frac{s}{\text{some}}
\end{align*}
Here we mark pure values with the unary prefix \(<b>\).

\[
\begin{array}{c}
\{{}\} \circ A\{b\} \quad \mid \quad \{B \circ { }\} \circ C \quad \mid \quad \{\} \circ C
\end{array}
\]

\(C \::= \circ A\{b\} \circ C \circ \{B \circ { }\} \circ C \circ \{\} \circ C\)

To enforce left-to-right evaluation in evaluation contexts:

Modify the Right rule:

\[
\begin{array}{c}
\{{}\} \circ A \quad \mid \quad \{B \circ { }\} \circ C \quad \mid \quad \{\} \circ C
\end{array}
\]

Encode this recursive definition of evaluation contexts:

\[
\begin{array}{c}
\{{}\} \circ A \quad \mid \quad \{B \circ { }\} \circ C \quad \mid \quad \{\} \circ C
\end{array}
\]

These structural postulates in multimodal categorial grammar:

**Evolution order**
Staging

The modal modality stands for quotation of programs. Any program can be quoted:

\[
\text{Quote (T)}: \frac{S \vdash \{\forall \langle t \rangle \langle b \rangle\}\_L}{S \vdash \{\forall \langle b \rangle\}_L}
\]

And any two programs can be concatenated:

\[
\text{Concat (K)}: \frac{S \vdash \{B \circ \forall \langle b \rangle\}_L}{S \vdash \{B \circ \forall \langle b \rangle\}_L}
\]

But only complete programs (with types of the form \(\forall \langle t \rangle\)) can be unquoted (run):

\[
\text{Run}: \frac{S \vdash \{\forall \langle t \rangle \langle b \rangle\}\_L}{S \vdash \{\forall \langle t \rangle\}_L}
\]

These stipulations interact to make correct linguistic predictions.

Nobody liked a woman's mother

(ambiguous)

*Anybody liked nobody's mother (unacceptable)

\(\langle t \rangle \in \mathcal{E}, \forall \in \mathcal{E}\)
Evaluation order and staging for linear scope

First of all, "nobody likes a woman's mother" can take linear scope. This is easy under left-to-right evaluation, because quantifiers evaluated earlier scope wider.

Ev}a}l}u}a}t}i}o}n} o}r}d}e}r} a}n}d} s}t}a}g}i}n}g} f}o}r} l}i}n}e}a}r} s}c}o}p}e
Moreover, "nobody likes a woman's mother" can also take inverse scope, because the answer type \( s \) returned by "nobody" can be unquoted.
Nevertheless, “anybody likes nobody’s mother” cannot take inverse scope, because the answer type $s^\langle b \rangle[d]$ cannot be unquoted.

Evaluation order and staging for polarity sensitivity
An old puzzle solved
An old puzzle solved, and a new one

A woman introduced everybody to somebody: Linear scope ok.

What is the type of "everybody"? Hint:

\[ \text{everybody} \quad \text{a woman} \quad \text{anybody} \quad \text{somebody} \quad \text{nobody} \]

\[ (\cdot s \downarrow du) \quad (\cdot s \downarrow du) \quad (\cdot s \downarrow du) \quad (\cdot s \downarrow du) \]

\[ \text{anybody} \quad \text{somebody} \quad \text{nobody} \quad \text{anybody} \]

\[ -s \quad +s \quad -s \quad +s \]

\[ s \quad -s \quad s \quad -s \]
An old puzzle solved, and a new one.
An old puzzle solved, and a new one

Nobody introduced everybody to somebody: Linear scope ok again!
Nobody introduced Alice to somebody: Linear scope bad.

Confirmation:

"Nobody introduced everybody to somebody": linear scope again.

A woman introduced everybody to somebody: Linear scope ok.

What is the type of "everybody"? Hint:

\[ (+s \langle du \rangle \mathbin|_{o}s \rightarrow \text{everybody} \]
\[ (s_{o} \langle du \rangle \mathbin|_{o}s \rightarrow \text{a woman} \]
\[ (+s \langle du \rangle \mathbin|_{o}s \rightarrow \text{somebody} \]
\[ (-s \langle du \rangle \mathbin|_{o}s \rightarrow \text{anybody} \]
\[ (-s \langle du \rangle \mathbin|_{o}s \rightarrow \text{nobody} \]

\[ -s \rightarrow _{o} s \]
\[ +s \rightarrow _{o} s \]

An old puzzle solved, and a new one
For linguistics:

Payoffs

• Staging side effects?
• Understand delimited continuations geometrically and logically.

For computer science:

• Relate (denotational) semantics to (operational) psycholinguistics?
• Cover more empirical data?

• Cover more empirical data.

3.1 Payoffs

Somebody liked everybody’s mother.

Nobody liked anybody’s mother.

*Alice liked anybody’s mother.

*Alice liked anybody’s mother.

*Alice liked everybody’s mother.

Alice liked Bob.

Outlines