Tracking Anaphors and Taking Scope with Dependent Types

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Dependencies are ubiquitously used and interpreted by natural language speakers.

- Plural unbound anaphora
- Donkey sentences
- Inverse linking constructions
- Possessive weak definites
- Long-distance indefinites

Unbound anaphora refers to instances where anaphoric pronouns occur outside the syntactic scopes of their quantifier antecedents

(1) Every man loves a woman. They (each) kiss them.

- The way to understand the second (anaphoric) sentence is that every man kisses the women he loves rather than those loved by someone else.
- The first sentence must introduce a dependency between each of the men and the women they love that can be elaborated upon in further discourse.

Inverse linking constructions refer to complex DPs which contain a quantified NP (QP), as in (2)

(2) a representative of every country

- ILC in (2) can be understood to mean that there is a potentially different representative for each country
  ✓ *every country* $>$ *a representative*
- The relational noun *representative* introduces a dependency between each of the countries and the representatives of that country.

Outline

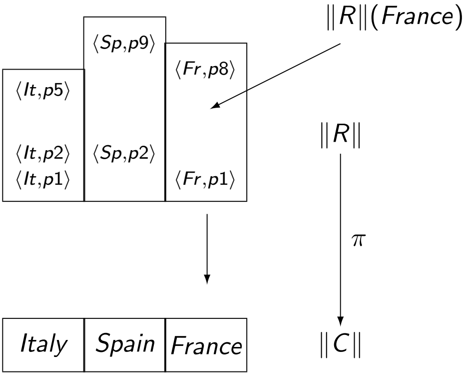
- Semantic system with dependent types - main features
  - Dependent types
  - Type-theoretic notion of context
  - Quantification over fibers
- Applications
  - Plural unbound anaphora
  - Donkey sentences and proportion problem
  - Inverse linking and preposition puzzle
- Combining dependent types with continuations

(Dependent) types and their interpretation

- The variables of our system are always typed: $x : X, y : Y, \ldots$
- Types are interpreted as sets: $\|X\|, \|Y\|, \ldots$
- Types can depend on the variables of other types: if x is a variable of the type X, we can have type $Y(x)$ depending on the variable x.
- The fact that Y is a type depending on X is modeled as a function $\pi : \|Y\| \to \|X\|$, the intended meaning being that each type $Y(x)$ is interpreted as the fiber $\|Y\|(a)$ of π over $a \in \|X\|$ (the inverse image of $\{a\}$ under π).

If c is a variable of the type of countries C, there is a type $R(c)$ of the representatives of that country.

$$c : C, r : R(c)$$



If we interpret type C as the set $\|C\|$ of countries, then we can interpret R as the set of pairs:

$$\|R\| = \{\langle a, p\rangle : p \text{ is the person from the country } a\}$$

equipped with the projection $\pi : \|R\| \to \|C\|$.

The particular sets $\|R\|(a)$ of the representatives of the country a can be recovered as the fibers of this projection (the inverse images of $\{a\}$ under π):

$$\|R\|(a) = \{r \in \|R\| : \pi(r) = a\}.$$

The interpretation of the structure:

$$c : C, r : R(c)$$

gives us access to the sets (fibers) $\|R\|(a)$ of the representatives of the particular country a only.

To form the set of all representatives, we need to use Σ type constructor; $\Sigma_{c:C} R(c)$ is to be interpreted as the disjoint sum of fibers over elements in $\|C\|$:

$$\|\Sigma_{c:C} R(c)\| = \bigsqcup_{a \in \|C\|} \pi^{-1}(a).$$

Language expressions (QPs, predicates) are interpreted relative to contexts of the form:

$$\Gamma = x : X, y : Y(x), z : Z(x, y), u : U, \ldots$$

Context is a partially ordered set of type declarations of the (individual) variables such that the declaration of a variable x of type X precedes the declaration of a variable y of type $Y(x)$.

Polymorphic interpretation of quantifiers and predicates

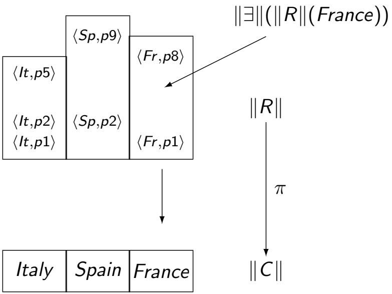
- Quantifiers and predicates are interpreted over various types (given in the context, e.g., *Country*, *Man*, . . .), and not over the universe of all entities.
- A QP like *some country* is interpreted over the type *Country*, i.e. *some country* denotes the set of all non-empty subsets of the set of countries

$$\|\exists\|(\|Country\|) = \{X \subseteq \|Country\| : \ X \neq \emptyset\}.$$

Quantification over fibers

We can quantify over the fiber of the representatives of France, as in *some representative of France*:

$$\|\exists\|(\|R\|(France)) = \{X \subseteq \|R\|(France) : \ X \neq \emptyset\}.$$



Dependencies given in the context determine the relative scoping of quantifiers.

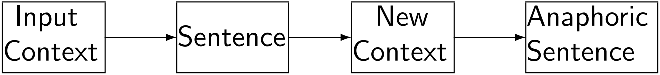
$$\Gamma = x : X, y : Y(x), z : Z(x, y), u : U, \ldots$$

✓ $Q_{1\ x:X} > Q_{2\ y:Y(x)}$
♯ $Q_{2\ y:Y(x)} > Q_{1\ x:X}$

A global restriction on variables is that each occurrence of an indexing variable be preceded by a binding occurrence of that variable - free undeclared variables are illegal.

Applications
Plural unbound anaphora

(1) Most men love a women. They (each) kiss them.



(1) Most men love a women. They (each) kiss them.

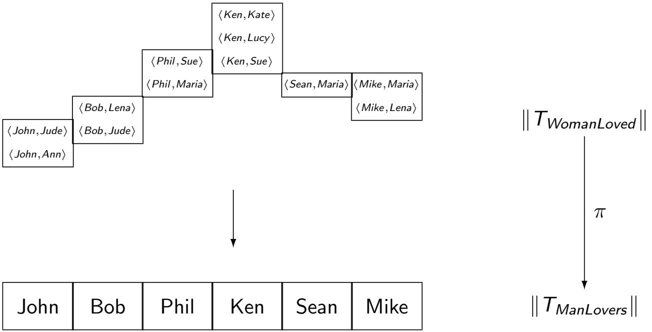
INPUT CONTEXT $\Gamma := \ m : Man, w : Woman$

$\varphi :=$ Most men love a women.

New Context

$$\Gamma_{\varphi} := t_m : T_{ManLovers}, t_w : T_{WomanLoved}(t_m)$$

They (each) kiss them.

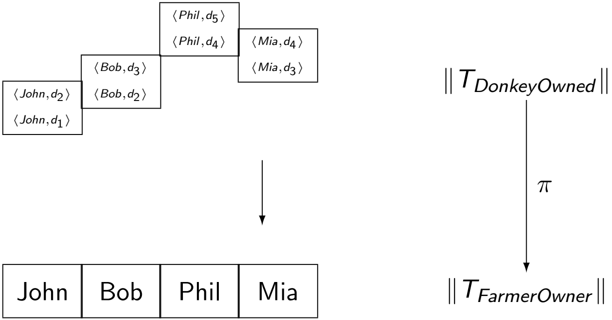


Applications

Donkey sentences and proportion problem

(1') Every farmer who own a donkey beats it.

Donkey sentences quantify over dependent types determined by the modified common noun (e.g. *farmer who owns a donkey*).



Montage-Style Semantics

- Sortal nouns (e.g. *man*) are interpreted as one-place relations (expressions of type $\langle e, t \rangle$).
- Relational nouns (e.g. *representative*) are interpreted as two-place relations (expressions of type $\langle e, \langle e, t \rangle \rangle$).

Dependent type analysis

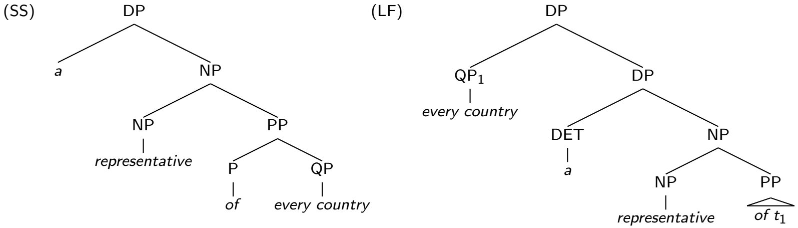
- Sortal nouns (e.g. *man*) are interpreted as types.
- Relational nouns (e.g. *representative*) are interpreted as dependent types.

Sortal nouns can undergo 'sortal-to-relational' shifts, as in *a man from every city*.

(2) a representative of every country

- ILC in (2) can be understood to mean that there is a potentially different representative for each country
  ✓ *every country* > *a representative* (inverse reading)
- ILC in (2) can be also understood to mean that there is some one person who represents all the countries
  ✓ *a representative* > *every country* (surface reading)

Standard LF-Movement Analysis



An alternative non-movement analysis of inverse readings

- Relational nouns (relational uses of sortal nouns) are modeled as dependent types.
- Here, *representative* (as in *a representative of a country*) is modeled as the dependent type $c : C, r : R(c)$. By quantifying over $c : C, r : R(c)$, we get the inverse ordering of quantifiers:

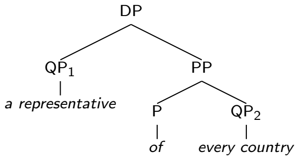
$$\forall_{c:C}\exists_{r:R(c)}.$$

$$\sharp \quad \exists_{r:R(c)} \forall_{c:C}$$

- The interpretation where $\exists$ outscopes $\forall$ is not available because the indexing variable c (in $R(c)$) is outside the scope of the binding occurrence of that variable.
- By making the type of representatives dependent on (the variables of) the type of countries, our analysis forces the inversely linked reading without positing any extra scope mechanisms.

Dependent Type Analysis
Compositional analysis

(IR)



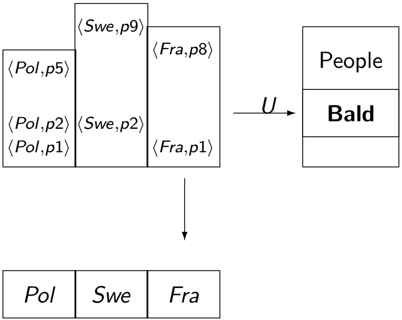
- The head nominal *representative* is modeled as the dependent type $c : C, r : R(c)$; the preposition *of* signals that *country* is a type on which *representative* depends; *country* is modeled as the type C.
- The complex DP *a representative of every country* is interpreted as the complex quantifier living on the set of all representatives

$$\|\forall_{c:C}\exists_{r:R(c)}\| = \{X \subseteq \|\Sigma_{c:C} R(c)\| :$$

$$\{a \in \|C\| : \{b \in \|R\|(a) : b \in X\} \in \|\exists\|(\|R\|(a))\} \in \|\forall\|(\|C\|)\}.$$

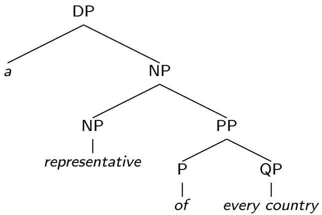
(3) **A representative of every country** is bald.

$$\|\forall_{c:C}\exists_{r:R(c)} Bald(r)\| = 1 \text{ iff } U^{-1}(\|Bald\|) \in \|\forall_{c:C}\exists_{r:R(c)}\|$$



Intuition: a person counts as a representative only in virtue of standing in a particular relationship with some country.

(SR)



- The relational noun *representative* is now interpreted standardly as the predicate defined on $\|P(erson)\| \times \|C(ountry)\|$.
- The complex NP *representative of every country* is then interpreted as the type/set of individuals who represent all the countries, and the DET *a* quantifies existentially over this set, yielding the surface ordering of quantifiers.

Puzzle: Why inverse readings are blocked with certain prepositions (e.g. *with*)?

(4) someone **with** every known skeleton key

- ILC in (4) can only be a statement about one person who happens to have every known skeleton key.

  ✓ *someone* $>$ *every known skeleton key*

  ♯ *every known skeleton key* $>$ *someone*

Solution: inverse readings are unavailable for ILCs with prepositions which induce dependencies corresponding to the surface ordering of the QPs.

- *a representative of (from, in) every country*:
  The 'dependent component' (*representative*) comes before the component on which it is dependent (*country*) - the dependency introduced, $c : C, r : R(c)$, forces the inversely linked interpretation.
- *a man with every key*:
  The potentially 'dependent component' (*key*) comes after the component on which it is dependent (*man*) - the dependency introduced, $m : M, k : K(m)$, corresponds to the surface ordering of the QPs.

$$\sharp \quad \forall_{k:K(m)} \exists_{m:M}$$

- By our global restriction on variables, the reading where $\forall$ outscopes $\exists$ is not available because the indexing variable m (in $K(m)$) is outside the scope of the binding occurrence of that variable.
- Thus, under the analysis proposed, the inverse interpretation is unavailable to the QP in the object position of *with*.

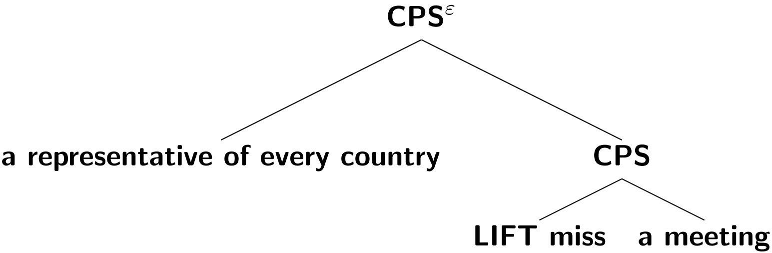
Difficulty: examples like *a problem with every account*

- *with* comes with a number of meanings, including:
  - 'having or possessing (something)',
  - 'accompanied by; accompanying',
- If the relation expressed is one of possession, as in our previous example, then the thing possessed depends on the possessor (as described above).
- If, however, the relation is that of accompanying, then the accompanying entity (problem) depends on the entity to be accompanied (account). Thus the dependency introduced is $a : A, p : P(a)$, forcing the inverse ordering of the QPs (in line with intuitions reported by native speakers).

(5) **A representative of every country** missed a meeting.

- Predicate *miss* is defined on $\|P(erson)\| \times \|M(eeting)\|$. By taking the inverse image of this set under function U, $U^{-1}(\|P\| \times \|M\|)$, we get the predicate *miss* defined on the product of representatives and meetings $\|\Sigma R\| \times \|M\|$.
- In order to combine with QPs a predicate gets lifted ('continuized'), i.e., *miss* of type $\mathcal{P}(\Sigma R \times M)$ will be lifted to an expression of type $\mathcal{CP}(\Sigma R \times M)$. $(\mathcal{P}(X) = X \to \mathbf{t}$ and $\mathcal{C}(X) = \mathcal{PP}(X))$
- The two readings for (5) are then derived, using either (left or right) of the two **CPS** transforms.

(5) **A representative of every country** missed a meeting.



$\varepsilon \in \{l, r\}$

$$\mathbf{CPS}^{l}, \mathbf{CPS}^{r} : \mathcal{C}(\Sigma R) \times \mathcal{CP}(\Sigma R) \longrightarrow \mathcal{C}(\mathbf{t})$$

given, for $M \in \mathcal{C}(\Sigma R)$ and $N \in \mathcal{CP}(\Sigma R)$, by

$$\mathbf{CPS}^{l}(M, N) = \lambda c_{:\mathcal{P}(\mathbf{t})}.M(\lambda r_{:\Sigma R}.N(\lambda g_{:\mathcal{P}(\Sigma R)}.c(g\ r)))$$

and

$$\mathbf{CPS}^{r}(M, N) = \lambda c_{:\mathcal{P}(\mathbf{t})}.N(\lambda g_{:\mathcal{P}(\Sigma R)}.M(\lambda r_{:\Sigma R}.c(g\ r))).$$

(5) **A representative of every country** missed a meeting.

- One empirical constraint on a theory of inverse linking is the so-called Larson's generalization (1985): QPs external to ILCs cannot take scope between the embedded and containing QPs.
- *a meeting* cannot take scope in between *every country* and *a representative* - the two interleaved interpretations are not possible for (5).
- Under our analysis, the inseparability of the two nested QPs falls out immediately.

The end

Thank You for Your Attention!