# ON THE SYNTACTIC-SEMANTIC ANALYSIS
# OF BOUND ANAPHORA

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## ABSTRACT

Two well-known phenomena in the area of pronoun binding are considered: Indirect binding of pronouns by indefinite NPs ("donkey sentences") and surface-syntactic constraints on binding ("weak cross-over"). A common treatment is proposed, and general consequences for the relation between syntactic and semantic processing are discussed. It is argued that syntactic and semantic analysis must interact in a complex way, rather than in a simple sequential or strict rule-to-rule fashion.

## 1. A SEMANTIC BINDING CONDITION: THE STANDARD ACCOUNT

We start our considerations on the mechanism of pronoun binding with the tentative formulation of a semantic binding condition in (1):

(1) A NP can bind pronouns in its scope

Taken that the "scope of a NP" means the scope of the (generalized) quantifier the NP translates to, and that pronouns are semantically represented by individual variables, Binding principle (1) more or less directly corresponds to the conditions on variable binding in predicate logic, and therefore has a great deal of intuitive plausibility with it. Accordingly, it is explicitly or silently assumed as the basic principle for pronoun binding in many theoretical and computational approaches to the semantics of natural language. Principle (1) makes correct predictions

for a wide range of natural language examples (we disregard the distinction between reflexive and non-reflexive pronouns throughout this paper). E.g., it explains why sentence (2) is fine, whereas (3) is impossible (binding is indicated in the usual way by co-indexing).

(2) [$_{NP}$Every student]$_i$ admires his$_i$ teacher

(3) * If [$_{NP}$every student]$_i$ admires his$_i$ teacher, he$_i$ is a fool

## 2. A REVISED SEMANTIC BINDING CONDITION: DRT

Binding principle (1) has turned out to be too restrictive. The indicated binding in Sentence (4), below, is fine although *a book* cannot take scope over the main clause where the bound pronoun occurs: It should not take wide scope for syntactic reasons (it occurs in a relative clause which is a clear case of an island construction), and if it did, the wrong semantics would result (globally, it functions as a universal rather than an as an existential quantifier, in (4)).

(4) Every professor who owns [$_{NP}$ a book]$_i$ reads it$_i$

This is the well-known "donkey-sentence problem" which motivated the DRT-style reformulation of natural language semantics (Discourse Representation Theory: Kamp 1981; File Change Semantics: Heim 1982). The solution that DRT provides for the donkey sentence

problem can be roughly outlined as follows: The common semantic function of non-anaphorical noun phrases is the introduction of a new discourse referent, which is in turn available for the binding of anaphoric expressions. Beyond this basic function, non-anaphorical noun phrases subdivide into genuine quantifiers (e.g., *every professor*), and non-quantificational NPs (e.g., the indefinite NP *a book*). Only the former bear scope. An *every*-NP, e.g., triggers the introduction of a complex condition of the form $K_1 \Rightarrow K_2$, where $K_1$ and $K_2$ are sub-DRSes representing the restriction and the scope of the quantification respectively. Indefinite NPs just contribute a new discourse referent (together with some descriptive material in terms of conditions on the discourse referent), which is placed in a larger structure. This larger structure can be the top-level DRS or some sub-DRS according to the sentence-internal environment of the analyzed NP.

Indefinite NPs do not have scope by themselves. It follows that Principle (1) cannot apply to Sentence (4), if it is taken literally. However, the model-theoretic interpretation for complex conditions is defined in a way that indefinite NPs share quantificational force and scope with their "host quantifier" (i.e., the quantificational NP whose representation contains the discourse referent introduced by the indefinite on the top-level of its restriction part). Accordingly, an indefinite NP should observe the restrictions on binding imposed by that larger quantificational structure. Therefore, the original binding principle (1) must be replaced by something like (5).

(5) A NP α can bind a pronoun β provided that β is in the scope of the host quantifier of α's discourse referent.

Actually, the revised binding principle (5) permits binding in (4), whereas the indicated binding in (6) is excluded under the preferred reading where *every professor* outscopes *a book*, which is in accordance with intuitions.

(6) * If every professor owns [NP a book]i, a student reads itj

Standard DRT tries to give a general account for the constraints on anaphoric binding by specifying an accessibility relation between positions in a complex DRS. The formulation of the revised binding principle in (5) is obviously neither general nor precise enough to replace the standard DRT treatment. We will come back to the point in Section 4.

## 3. A SYNTACTIC BINDING CONDITION

The scope of noun phrases is not determined by their surface syntactic position.

(7) Every professor owns a book

Expressed in terms of conventional predicate logic or generalized quantifier theory, Sentence (7) is ambiguous between a narrow-scope reading and a wide-scope reading of the existential NP *a book*. The former corresponds to the constituent structure of (7), the latter is due to a "delayed application" of the existential NP, which can be brought about by different syntactic and semantic techniques (e.g., Quantifier Raising: May 1985, Cooper Storage: Cooper 1983).

Scope variation leads to an additional difficulty with the binding principle (1): If NPs (i.e., quantifier terms, on the standard account) are applied in situ, their semantic scope precisely parallels their c-command domain in surface structure. Examples of postponed quantifier application disturb the parallelism and by that provide evidence that the syntactic c-command concept is relevant for binding in addition to the semantic notion of scope.

(8) *A student of hisi admires [NP every teacher]j

In Sentence (8), *every teacher* may take scope over the indefinite NP *a student of his*. That the pronoun *his* is in the scope of

the quantifier is obviously insufficient to license binding, which seems to be blocked by the fact that the object NP does not c-command the pronoun. This phenomenon, the so-called "Weak-Crossover Effect", shows that the semantic principle (1) is too weak to properly constrain anaphoric binding, and has lead to a syntactic binding principle the classical formulation of which is given in (9) (cf. Reinhart 1983, Williams 1986).

**(9) A NP can bind pronouns in its c-command domain.**

As more recent theoretical work has shown, the c-command condition is only an approximation to reality (cf. Stowell 1989). However, the precise definition of the c-command relation and the syntactic condition as a whole is not crucial for the argument. The important point is that anaphoric binding is apparently dependent on genuinely syntactic facts: The decision of whether a pronoun can be bound by a NP cannot be made on the basis of semantic information only. There are basically two possible ways out: On the one hand, one can pass the task of specifying anaphoric relations completely to syntax (this is the answer of GB grammarians). On the other hand, one can make certain portions of syntactic information available for semantic processing (proposals are made in Pollack/Pereira 1988, Latecki/Pinkal 1990). The choice between the two solutions seems to some extent to be a matter of taste: Plausibility reasons as well as efficiency considerations for natural language processing speak against the first solution. The fact that one has to import and process syntactic information within semantic interpretation seems to be a certain methodological drawback. I will come back to the question after having discussed a further complication in the next section.

## 4. BINDING, SYNTACTIC AND SEMANTIC CONDITIONS TOGETHER

In the last section, the phenomenon of

scope ambiguity and its consequences for anaphoric binding have been considered on the background of the standard semantic framework. Obviously, a two-reading analysis for sentences like (7) must be provided in a DRT-based analysis, as well, although it must be accounted for in a slightly different way. The two readings of (7) do not differ in the relative scope order of two quantifiers. Rather, the difference is that on the narrow scope reading, the discourse referent introduced by *a book* occurs inside the complex condition established by the universal NP (its host quantifier), whereas on the wide-scope reading it occurs on the top-level of the DRS.

Scope ambiguities are not treated in the original DRT version; they are difficult to model with procedural DRS construction rules that operate on surface syntactic structures. There is however a convenient and straightforward way to combine the DRT formalism with the technical means of lambda-abstraction. (10) indicates how representations of the NPs *every professor* and *a book* as partially instantiated DRSes can be given using lambda-abstraction over predicative DRSes (The latter are obtained from standard DRSes by abstraction over a discourse referent. The "⊕" sign in (10) is an operator which merges two DRSes.)

(10) $\lambda$ **S**

| x<br>professor (x) | $\Rightarrow$ **S(x)** |

$\lambda$ **R**

| y<br>book (y) | $\oplus$ **R(y)** |
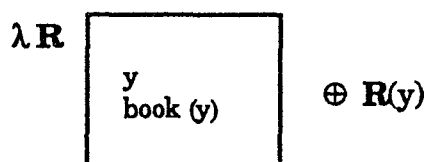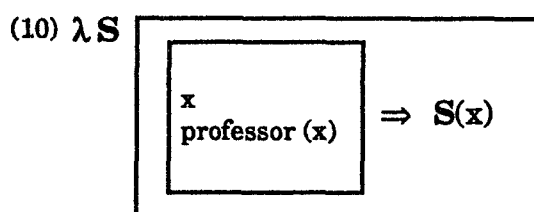
One effect of this modification of DRT is that semantic representations can be constructed compositionally, in a bottom-up fashion. Another consequence is that

the standard techniques for delayed application become available in the DRT framework.

Not surprisingly, we run into difficulties with the revised semantic binding condition (5) in connection with the weak crossover cases, as soon as we treat scope ambiguities in a DRT-style analysis. According to (5), both the standard weak crossover example (8) and the inverted donkey sentence (11) should be acceptable.

(11) *Its$_i$ readers admire every professor who writes [$_{NP}$ a book]$_i$

Since the discourse referent provided by *a book* takes its place at the top level of the restriction part of the *every*-NP, the indefinite should count as a proper antecedent for the pronoun on the reading where the *every*-NP takes wide scope over the whole sentence. If in addition the syntactic binding principle (9) is observed, cases like (8) and (11) are correctly ruled out: Neither *every teacher* in (8) nor *a book* in (11) c-command the respective pronouns. But unfortunately, also those cases of anaphoric binding are blocked which provided the original motivation for DRT, namely the donkey-sentence cases discussed above. In sentence (4), the antecedent NP *a book* definitely does not c-command the pronoun *it*.

Examples like (8) and (11) demonstrate that a syntactic condition on binding has to be observed, also under a DRT-based analysis. The considerations of the last paragraph however show that this syntactic condition cannot be c-command between antecedent and pronoun. A modification of the syntactic binding principle (9) appears to bring about the right predictions: It is not the antecedent which must c-command the pronoun, but the quantificational NP, the host operator of the antecedent's discourse referent. In (4), the pronoun *it* is in the c-command domain of the NP *every professor who owns a book*, whereas in (8) and (11), where binding is impossible, the universal NP does not c-command the pronoun.

In (12), a revised version of the syntactic principle (9) is proposed.

(12) A NP $\alpha$ can bind a pronoun $\beta$ provided that $\beta$ is in the c-command domain of the host quantifier of $\alpha$'s discourse referent.

The revised principles (5) and (12) together capture the complex conditions on binding in donkey sentences. They are not general enough, however, for they do not say anything about the binding conditions on indefinites which are not associated to the restriction of a genuine quantifier term. In the following, a more dynamic formulation of the binding rule is given, which has larger coverage and contains the interaction of quantification and indefinites in donkey sentences as a special case.

We assume that the immediate effect of the analysis of a pronoun is just the introduction of a discourse referent, which is also marked as a candidate for binding. Each semantic representation contains together with the DRS information about the unbound pronominal discourse referents. Binding can take place whenever a NP denotation (quantificational or indefinite) is applied to a predicative DRS, according to (13).

(13) When the denotation $\alpha$ of a noun phrase A is applied to a predicative DRS $\lambda uK$, any top-level discourse referent of $\alpha$ can bind an unbound pronominal discourse referent of K, provided that the respective pronoun is in the c-command domain of A.

Rule (13) also accounts for the different status of (14) and (15), where (15) is excluded by the syntactic constraint.

(14) [$_{NP}$A teacher]$_i$ admires a student of his$_i$
(15) *A student of his$_i$ admires [$_{NP}$ a teacher]$_i$

## 5. A GENERAL RESULT FOR SYN-TACTIC-SEMANTIC PROCESSING

The results of the last section have consequences for the over-all view of syntactic-semantic processing of natural-language sentences containing anaphoric pronouns. The revised binding principle (12) relates the pronoun β and its antecedent α indirectly, by making reference to the quantifier term γ which eventually contains the discourse referent of the antecedent NP. Now, the relation between the pronoun β and the host quantifier γ is a syntactic one, whereas the relation between γ and the antecedent α is a semantic relation: Up to which position in the DRS the discourse referent eventually percolates will only turn out, when the corresponding portion of semantic analysis is done.

This means that the decision between the two ways of specifying anaphoric relations which were mentioned at the end of Section 3 is no longer a matter of taste: The linguistic data force a choice in favor of the second alternative.

The possible anaphoric relations in a sentence cannot be specified by the syntactic component only: Some amount of semantic processing must precede the c-command check (in order to know which constituents are to be checked). And they cannot be specified by the semantic component only, since there are obviously surface-syntactic constraints on binding.

Therefore the strict sequential model of syntactic and semantic processing: co-indexing in the syntactic component and strictly deterministic semantic interpretation, which is explicitly or implicitly favored by adherents of the Government-and-Binding approach, cannot be maintained (if we disregard the theoretically possible, but highly non-deterministic method of random indexing and semantic filtering). Also, anaphora cannot be treated as a matter of syntax-free semantics. Syntax and semantics must interact in a non-trivial way in order to determine what an admissible antecedent for an anaphoric pronoun is.

## 6. IMPLEMENTATION

The described interaction between syntax and semantics suggests a processing model with independent, but freely interacting modules in the spirit of principle-based parsing. Actually, an implementation of a principle-based NL system with a semantic module covering the phenomena discussed in this paper in in preparation. It will basically be an extension of the system described in Millies (1990).

A more conventional system for DRT-based syntactic-semantic analysis that generates admissible scope readings has been implemented in Quintus Prolog at the University of Hamburg, in a DCG style grammar system. A declarative version of DRT is used, which bears certain similarities to the one described in Zeevat (1989). Semantic interpretation is carried out in parallel to syntactic analysis. Scope readings are produced using a modified version of Cooper Storage, which is equivalent in its results to Nested Cooper Storage (Keller 1988) and the Hobbs-Shieber-Algorithm (Hobbs/ Shieber 1987), but employs an efficient indexing technique to check violations of free variable constraint and syntactic island constraints.

An extension of the system which checks the admissibility of anaphoric relations is under work at Saarbrücken University. c-command is checked by another version of the above-mentioned indexing technique (described in Latecki 1990) Relevant syntactic information is imported into semantics by attaching index sets to term phrases in the storage; it is activated at the time of the (delayed) application of the quantifier term. The system for treating quantifier scope as well as its extension to anaphoric binding are described in Latecki/Pinkal (1990).

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