Integrating Binding Principles Into Formal Grammar Processing: an HPSG Account

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Abstract

Departing from the mainstream, syntax-driven approach to binding principles, we argue for an alternative, semantics-oriented rationale for these principles. Under this new understanding of the nature of grammatical constraints on anaphoric binding, these constraints are viewed as contributing to circumscribe the contextually determined semantic value of anaphoric nominals. This conceptual shift helps to find a fully fledged integration of binding principles in the HPSG lean description formalism where these constraints are entered in the grammar as part of the information kept at the lexical entries of anaphoric expressions.

1. Introduction

Since the so called integrative approach to anaphora processing was set up in late eighties,[1] it became common wisdom that factors determining the antecedents of anaphors divide into preferences and filters. The first exclude impossible antecedents and help to determine the set of antecedent candidates; the latter help to pick up the most likely candidate, the one that will end up being proposed as the antecedent.

Grammatical constraints on anaphoric binding, known as binding constraints or binding principles, are a most significant subset of such filters.[2] They delimit the relative positioning of anaphoric nominals and their admissible antecedents in grammatical geometry. From an empirical perspective, they stem from quite robust generalizations and exhibit a universal character, given their parameterized validity across natural languages. From a conceptual point of view, in turn, the relations among binding constraints involve non-trivial symmetry, which lends them a modular nature. Accordingly, these constraints have been seen as one of the most robust modules of grammatical knowledge, usually referred to as binding theory.

In contrast to this, the formal and computational handling of the empirical generalizations encoded in binding constraints has presented considerable resistance when it comes to their integration into grammar.

As discussed in the literature (Fong, 1990), the mainstream methodology for verifying the compliance of grammatical representations with binding constraints, based on exhaustive and overgenerating indexation (Chomsky, 1981), requires extra-grammatical processing steps of non-tractable computational complexity which, moreover, deliver a forest of indexed trees to anaphor resolvers and reference processing modules.

More recently, constraint-based grammatical frameworks do not offer yet fully satisfactory alternatives in this respect. As we will discuss at length in our presentation, while requiring special purpose extensions of the description formalism, LFG account of binding theory (Dalrymple, 1993) ensures only a partial handling of binding constraints.

As for HPSG, despite the fact that binding constraints did not receive a fully fledged encoding in its basic description formalism, this seems not to have attracted significant attention. In the nine page Appendix of (Pollard and Sag, 1994), the fragment of grammar developed along this book received an implementation in the adopted formalism. Binding constraints escaped however such encoding. While noting that these constraints are waiting to be accommodated into HPSG grammars, Koenig (1999) suggestion for extending the basic formalism with inside-out constraints, but in particular Bredenkamp (1996) and Backofen *et al.* (1996) elaboration on this issue, imply that some kind of essential limitation of the formalism might have been reached: A suggestion we will seek to contradict in this presentation.

Our primary goal here is to bridge the gap between the grammatical nature of binding constraints and their full integration into formal grammar specification and processing. In particular, we aim at achieving this by using a lean grammatical description formalism (by using the basic HPSG one), and by ensuring both an empirically adequate specification and a computationally tractable verification of binding constraints.

As a first step, we argue for a different view of the nature of binding constraints. On the basis of such discussion, and adopting a quite simple, underspecified representation of the semantics of anaphoric nominals, we introduce the rationale of new, lexicalist account of binding constraints. In the light of this methodology, we show then how binding constraints can be fully integrated into grammar by providing a modular specification of binding theory in terms of the current HPSG description formalism.

[1] (Carbonell and Brown, 1988), (Rich and LuperFoy, 1988), (Asher and Wada, 1989).
[2] For a definition of binding principles see the Annex.

2. A Semantics-driven Twist

Binding constraints have been basically viewed as well-formedness conditions, thus belonging to the realm of Syntax: "[they] capture the distribution of pronouns and reflexives" (Reinhart, 1993, p.657). In line with (Gawron and Peters, 1990), however, we think these constraints should rather be understood as conditions on semantic interpretation, given they delimit (non-local) aspects of meaning composition, rather than aspects of syntactic composition.

Like other kind of constraints on semantic composition, binding constraints impose conditions on the interpretation of certain expressions — anaphors, in the present case — based on syntactic geometry. This cannot be seen, however, as implying that they express grammaticality requirements. By replacing, for instance, a pronoun by a reflexive in a sentence, we are not turning a grammatical construction into an ungrammatical one, even if we assign to the reflexive the antecedent adequately selected for the pronoun. In that case, we are just asking the hearer to try to assign to that sentence a meaning that it cannot express, in the same way as what would happen if we asked someone whether he could interpret *The red book is on the white table* as describing a situation where a white book is on a red table.

In the example above, given how they happen to be syntactically related, the semantic values of *red* and *table* cannot be composed in a way that their sentence could be used to describe a situation concerning a red table, rather than a white table. Likewise, if we take *John thinks Peter shaved him*, given how they happen to be syntactically related, the semantic values of *Peter* and *him* cannot be composed in a way that this sentence could be used to describe a situation where John thinks that Peter shaved himself, i.e. Peter, rather than a situation where John thinks that Peter shaved other people, e.g. Paul, Bill, etc., or John himself. The basic difference between these two cases is that, while in the first the composition of the semantic contributions of *white* and *table* (for the interpretation of their NP *white table*) is constrained by local syntactic geometry, in the latter the composition of the semantic contributions of *John* and *him* (for the interpretation of the NP *him*) is constrained by non-local syntactic geometry.

This discussion leads one to consider that, an anaphor should be semantically specified in the lexicon as a function whose argument is a suitable representation of the context — providing a semantic representation of the NPs available in the discourse vicinity —, and delivers an update both of its anaphoric potential — which is instantiated as the set of its grammatically admissible antecedents — and of the context, against which other NPs are interpreted. Naturally, all in all, there will be four of such functions available to be lexically associated with anaphors, each corresponding to one of the different four classes of anaphors, in accordance with the four binding constraints A, B, C or Z (Xue *et al.*, 1994), (Branco and Marrafa, 1999).

3. The Rationale

This rationale is in line with the insights of (Johnson and Klein, 1990) concerning the processing of the semantics of nominals, and also the spirit (but by no means the letter) of the dynamic semantics framework (Chierchia, 1995). It provides a suitable ground for a lexicalist account of the specification and verification of binding constraints.

The updating of the context by an anaphoric nominal *n* may be seen as consisting simply in the incrementing of a suitable representation of the former with a copy of the reference marker (Kamp and Reyle, 1993) of *n*.

The updating of the anaphoric potential of *n*, in turn, delivers a representation of the contextualized anaphoric capacity of *n* under the form of the list of reference markers of its grammatically admissible antecedents. This list results from the binding constraint, associated to *n*, being applied to the relevant representation of the context of *n*. This list of reference markers collects the antecedent candidates, and its elements will be submitted to other filters and preferences in the process of anaphor resolution so that one of them ends up being chosen as the antecedent.

Finally, the input context is coded under the form of a set of three lists of reference markers, **A**, **Z** and **U**. **A** is the list with the reference markers of the local o-commanders of *n* ordered according to their relative grammatical obliqueness; **Z** includes the o-commanders of *n*, possibly observing multiclausal obliqueness hierarchy; and **U** is the list of all reference markers in the discourse context, including those not linguistically introduced.

Given this setup, the role of binding constraints in circumscribing the anaphoric potential of nominals is explicitly acknowledged. The particular contextualized instantiation of that potential and the verification of binding constraints coincide and consist in a few simple steps. If the nominal *n* is a short-distance reflexive, its semantic representation is updated with **A'**, where **A'** contains the reference markers of the o-commanders of *n* in **A**. If *n* is a long-distance reflexive, its semantic representation includes **Z'**, such that **Z'** contains the o-commanders of *n* in **Z** . If *n* is a pronoun, $\mathbf{B}=\mathbf{U}\backslash((\mathbf{A'}\}\cup[\text{r-mark}_n])$ is encoded into its representation, where r-mark$_n$ is the reference marker of *n*. Finally if *n* is a non-pronoun, its updated semantics keeps a copy of $\mathbf{C}=\mathbf{U}\backslash((\mathbf{Z'}\}\cup[\text{r-mark}_n])$.[3]

While following an empirically grounded conception of binding constraints, this rationale supports a tractable algorithm that embodies, and harmonizes, the major contributions of previous proposals concerning the verification of these constraints. It builds on strategies for the packaging of anaphoric ambiguity (vz. list of reference markers) and non-local context (vz. set of lists of reference markers) (Correa, 1988), (Giorgi *et al.*, 1990). Concomitantly, it supposes the lexicalization of binding constraints (Dalrymple, 1993), (Johnson, 1995).

[3] Note that the lists **A'**, **Z'**, **B** and **C** collect the reference markers that are antecedent candidates at the light only of the binding constraints, which are relative positioning filters in the process of anaphor resolution. Their elements have to be submitted also to the other filters and preferences in this process, in particular those requiring similarity of morphological features. In this respect we deviate from the proposal of (polsag:hpsg94), where the token-identity of indices, and a fortiori similarity of morphological features, is meant to be forced upon the anaphor and its antecedent in tandem with the relevant binding constraint.

Moreover, this is achieved avoiding the above reported problems related to the proliferation of grammatical representations, as well as the problems of ensuring a complete empirical coverage. Crucially, under this lexicalist approach, the binding constraint of each anaphor is now enforced independently of how the surrounding anaphors happen to be resolved. This implies that there is no need to anticipate all the different hypothetical resolution results for all the relevant anaphors with a process of exhaustive coindexation. It becomes also clear that cases of undesired transitive anaphoricity should be handled by other filters during the anaphor resolution process.[4]

Last but not least, computational tractability is ensured given the polynomial complexity of the underlying verification algorithm. Let n be the number of words in the input string to be parsed, which for the sake of the simplicity of the argument is assumed to be made only of anaphors. Assume also that the sets **A**, **Z** and **U** are available at each node of the parsed tree via copying or via list appendings, a process which takes constant time. At worst, the operations involved at each leaf node of the tree to obtain one of the sets **A'**, **Z'**, **B** or **C** are list copying and list appending operations, performed in constant time; extraction of the predecessors of an element in a list, which is of linear complexity; or at most one list complementation, which can be done in time proportional to $n\ log(n)$. This gives the whole process of verifying binding constraints in a string of length n the worst case complexity of $O(n^2\ log(n))$.

4. A Draft Binding Theory in HPSG

This refreshed view of binding constraints can receive an easy and principled integration into constraint-based grammar. In what follows, we outline how binding theory can be handled in basic HPSG.

As a proposal for that integration, we designed a simple extension of the UDRT semantics component for HPSG of (Frank and Reyle, 1995). This component is encoded as the value of feature CONT(ENT), which is now enhanced with feature ANAPH(ORA). This new feature keeps information about the anaphoric potential of the corresponding nominal n: its subfeature ANTEC(EDENTS) keeps record of how that potential is updated when the anaphor enters a grammatical construction; and its subfeature R(EFERENCE)-MARK(ER) indicates the reference marker of n, to be contributed to the context.

(1)

$$\left[\begin{array}{ll} \text{LOC}\,|\,\text{CONT} & \left[\begin{array}{ll} \text{LS} & \left[\begin{array}{ll}\text{L-MAX} & \boxed{1}\\ \text{L-MIN} & \boxed{1}\end{array}\right]\\ \text{SUBORD} & \{\ \}\\ \text{CONDS} & \left\{\left[\begin{array}{ll}\text{LABEL} & \boxed{1}\\ \text{ARG-R} & \boxed{2}\end{array}\right]\right\}\\ \text{ANAPH} & \left[\begin{array}{ll}\text{R-MARK} & \boxed{2}\\ \text{ANTEC} & \textit{principleB}(\boxed{4},\ \boxed{3},\ \boxed{2})\end{array}\right]\end{array}\right]\\ \text{NONLOC}\,|\,\text{BIND} & \left[\begin{array}{ll}\text{LIST-A} & \boxed{3}\\ \text{LIST-B} & \textit{list}\\ \text{LIST-U} & \boxed{4}\\ \text{LIST-LU} & \boxed{2}\end{array}\right]\end{array}\right]$$

On a par with this extension, and still assuming (Pollard and Sag, 1994) feature geometry as a starting point for the sake of simplicity, also the NONLOC value is extended with a new feature, BIND(ING), with subfeatures LIST-A, LIST-Z, and LIST-U. These lists provide a specification of the relevant context and correspond to the lists **A**, **Z** and **U** above. Subfeature LIST-LU is a fourth, auxiliary list for encoding the contribution of local context to the global, non-local context.[5]

Given this adjustment to the grammatical geometry, the lexical definition of a pronoun, for instance, will include the SYNSEM value described in (1).

In this feature structure, the contribution of its reference marker for the context by the pronoun is ensured via token-identity between R-MARK and LIST-LU values. The piling up of this reference marker in the global LIST-U value is determined by a new HPSG principle specific to binding (cf. (2) below).

The binding constraint associated to pronouns, in turn, is specified as the relational constraint *principleB*. This relational constraint is responsible for the updating of the anaphoric potential of the pronoun as it enters a grammatical construction. When its arguments are instantiated, this constraint returns list **B** as the value of ANTEC. It is defined to take (in first argument) all markers in the discourse context, given in LIST-U value, and remove from them both the local o-commanders (included

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[4] Consider sentence *John said that he shaved him*. Ignoring how other anaphors are resolved, in the light of binding constraint B, one of the possibilities is that *he* takes *John* as its antecedent; likewise, *him* can take *John* as its antecedent. Nevertheless, if *he* actually ends up resolved against *John*, the latter cannot be the antecedent of *him*, and vice-versa. This specific resolution both of *he* and *him* blocks two anaphoric relations that would otherwise have been admissible. It induces a contingent violation of binding constraint B due to an accidental, transitive anaphoric relationship between *he* and *him*.

[5] Given this extension, the coordination constraint requiring token-identity of SLASH values of conjuncts should be refined in order to involve only its original subfeatures INHER and TO-BIND.

in second argument) of the pronoun and the marker corresponding to the pronoun (in third argument).

The SYNSEM value of other anaphors, ruled by Principles A, C or Z, are similar to the one above.[6] The crucial difference lies in the relational constraints in ANTEC value. These constraints encode the adequate binding principles — *principleA*, *principleC* and *principleZ* — and return the updated anaphoric potential under the form of a list — **A'**, **C** or **Z'**, respectively —, along the lines discussed in the previous Section.

We turn now to the specification of the context, i.e. the values of LIST-A, LIST-Z, LIST-U and LIST-LU. This representation can be handled by means of a new HPSG principle we termed the Binding Domains Principle. This principle consists of three clauses constraining signs with respect to these lists of reference markers. Due to the space limitations of this extended abstract, we illustrate only part of this principle in full detail below, with its Clause I, for LIST-U and LIST-LU (a full version of Binding Domains Principle will be discussed in the presentation):

(2) **Binding Domains Principle**, Clause I

i. LIST-LU value is identical to the concatenation of LIST-LU values of its daughters in every sign;
ii. LIST-LU and LIST-U values are token-identical in a sign of sort *discourse*;
iii. i. LIST-U value is token-identical to each LIST-U value of its daughters in a non-NP sign;
  ii. in an NP sign *k*:
  - in Spec-daughter, LIST-U value is the result of removing the elements of LIST-A value of Head-daughter from the LIST-U value of *k*;
  - in Head-daughter, LIST-U value is the result of removing the value of R-MARK of Spec-daughter from the LIST-U value of *k*.

By virtue of (i.), LIST-LU collects up to the outmost sign, which is designed to be of sort *discourse*, the markers contributed for the context by the different NPs. Given (ii.), they are passed to LIST-U at this sign . And (iii.) ensures that they are propagated to every NP. Subclause (iii.ii) is meant to avoid a self-reference loop due to anaphoric interpretation, which is known in the literature as the i-within-i effect.

The top ontology was thus extended with the new subsort *discourse*: *sign* ≡ *word* ∨ *phrase* ∨ *discourse*. This new type of object corresponds to sequences of sentential signs, for which a specific Immediate Dominance schema has to be provided, and at which reference markers from the non-linguistic context may be introduced.

As to the other two Clauses of Binding Domains Principle, they are designed to constraint LIST-A and LIST-Z values. Briefly, Clause II ensures that LIST-A value is passed from the lexical head to its successive projections, and also from the head-daughters to their arguments. Concomitantly, at the lexical entry of any predicator *p*, LIST-A is defined as the concatenation of the R-MARK values of the subcategorized arguments of *p*, specified in its ARG-S value. Note that exemption occurs when *principleA*([1], [2]) is the empty list, in which case the subsequent anaphor resolver operating on that list should find an antecedent for the reflexive outside any binding constraint (Pollard and Sag, 1994, p.263)

Clause III ensures that, at the top node of the grammatical representation, LIST-Z is set up as the LIST-A value of that sign. Moreover, it ensures that LIST-Z is successively incremented at the suitable downstairs nodes — those defining successive locality domains for binding — by appending, in each of these nodes, LIST-A value with LIST-Z value of the upstairs node.[7]

5. Conclusions

Departing from the mainstream, syntax-driven paradigm, we proposed an alternative, semantics-based rationale for the specification of binding constraints. Under this rationale, these constraints are viewed as contributing to circumscribe the contextually determined semantic value of anaphoric nominals. This approach helped to find a empirically correct and computationally tractable integration of binding constraints into formal grammars.

6. Annex

The empirical determination of the generalizations known as binding constraints, or binding principles, has been the focus of intense research in past decades, from which a binding theory of steadily increasing empirical adequacy has emerged. Many diferent aspects, concerning e.g. a parameterizable definition of local domain, the occurrences of reflexives where they are exempt from their binding constraints, the subject-orientedness of some anaphors, or the degree of universality of binding theory, just to refer a few examples, have been the subject of intense scrutiny. In this article, as a starting point for the formal and computational issues we want to address, we follow the definition of binding constraints proposed by Pollard and Sag (1994, Chap.6). Subsequent developments of this proposal (vd. (Xue *et al.*, 1994) and (Branco and Marrafa, 1999)) hypothesize that there are four such constraints, which are presented below, together with some illustrative examples.

(i) Principle A:
A locally o-commanded short-distance reflexive must belocally o-bound.
[Lee$_i$'s friend]$_j$ thinks [[Max$_k$'s neighbor]$_l$ saw himself $_{*i/*j/*k/l}$].

(ii) Principle Z:
An o-commanded long-distance reflexive mustbe o-bound.
[O amigo$_i$' do Rui]$_j$ acha que [[o vizinho$_k$ do Pedro]$_l$ gosta dele próprio $_{*i/j/*k/l}$].

[6] Binding constraints for non-lexical anaphoric nominals are lexically stated in the corresponding determiners.

[7] From this description of Binding Domains Principle, it follows that the locus in grammar for the parameterization of what counts as a local domain for a given language is the specification of Clause II and III for that language.

[Rui$_i$'s friend]$_j$ thinks [[Pedro$_k$'s neighbor]$_l$ saw him/himself $_{*i/j/*k/l}$].

(iii) Principle B:
A pronoun must be locally o-free.
[Lee$_i$'s friend]$_j$ thinks [[Max$_k$'s neighbor]$_l$ saw him $_{i/j/k/*l}$].

(iv) Principle C:
A non-pronoun must be o-free.
[Lee$_i$'s friend]$_j$ thinks [[Max$_k$'s neighbor]$_l$ saw the student $_{i/*j/k/*l}$].

Binding constraints are defined on the basis of a few auxiliary notions.

The notion of *o-binding* is such that x o-binds y iff x o-commands y and x and y are coindexed, where coindexing is meant to represent anaphoric links.

O-command is a partial order under which, in a clause, the Subject o-commands the Direct Object, the Direct Object o-commands the IndirectObject, and so on, following the usual obliqueness hierarchy of grammatical functions; in a multiclausal sentence, the upward arguments o-command the successively embedded arguments. The o-command relation is defined on the basis of obliqueness hierarchies successively embedded along the relation of subcategorization: "Y o-commands Z just in case either Y is less oblique than Z; or Y o-commands some X that subcategorizes for Z; or Y o-commands some X that is a projection of Z." (Pollard and Sag, 1994, p.279).

The notion of *local domain* for an anaphoric nominal *n* involves the partition of sentences and associated grammatical geometry into two zones of greater or less proximity with respect to *n*. Typically, the local domain coincides with the selectional domain of the predicator subcategorizing the anaphor. In some cases, there may be additional requirements that the local domain is circumscribed by the first upward predicator that happens to be finite, bears tense or indicative features, etc.

There are anaphors that are subject-oriented, in the sense that they only take antecedents that have the grammatical function Subject. Some authors (e.g. Dalrymple (1993)) assume that this should be seen as an intrinsic parameter of binding constraints and aim at integrating it into their definition. In this point we follow previous results of ours reported in (Branco, 1996, and Branco and Marrafa, 1997), where the subject-orientedness of anaphors is argued to be, not an intrinsic feature of binding constraints, but one of the surfacing effects resulting from the nonlinear obliqueness hierarchy associated with some predicators (or with all of them in some languages).

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