Unavoidable Ill-nestedness in Natural Language and the Adequacy of Tree Local-MCTAG Induced Dependency Structures

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Abstract

Within generative approaches to grammar, characterizing the complexity of natural language has traditionally been couched in terms of formal language theory. Recently, Kuhlmann (2007) and collaborators have shown how derivations of generative grammars can be alternately represented as dependency graphs. The properties of such structures provide a new perspective of grammar formalisms and different metric of complexity. The question of complexity of natural language can be recast in dependency structure terms. Ill-nested structures have been assigned to some examples in the literature (Boston et al, 2009, Maier and Lichte, 2009), but the availability of well-nested alternatives prevents the use of these examples to claim that ill-nestedness is an unavoidable linguistic reality. This paper claims that two examples, one German and one Czech, are unavoidably ill-nested, indicating that ill-nestedness is indeed unavoidable in natural language. We conclude that formalisms that generate only well-nested structures, such as TAGs, are not quite powerful enough. However, the tree-local multi-component extension to TAG does generate ill-nested structures, providing just the appropriate amount of complexity in dependency structure terms for characterizing natural language.

1 Introduction

Within generative approaches to human grammar, characterizing the complexity of natural language has traditionally been couched in terms of formal language theory. For some time, it appeared that the weak generative capacity of context free grammars might be adequate for capturing natural language. After the linguistic patterns reported by Shieber (1985) and Culy (1985) indicated that this was not so, Joshi (1985) proposed that a grammar that adequately described natural languages should have four particular properties, dubbing the class of such grammars as mildly context-sensitive. A number of independently developed grammar formalisms not only had these properties but turned out to be weakly equivalent (Joshi et al., 1991).

Recently, Kuhlmann (2007) and collaborators have connected the generative grammar approach with the dependency grammar approach, where linguistic analysis is based on word-to-word relationships. In particular, two properties that are naturally defined over dependency structures, *gap degree* (a measure of discontinuity) and *well-* vs. *ill-nestedness* (whether interleaving substructures are permitted) carve out classes of structures that are systematically related to the derivations of generative grammars. For example, derivations in CFGs correspond to well-nested, gap degree zero dependency structures while derivations in lexicalized Tree Adjoining Grammars (LTAGs) correspond to well-nested, gap degree ≤ 1 dependency structures (Bodirsky et al., 2005).

These properties of associated dependency structures provide a new perspective of generative grammars and a different metric of complexity. The question of the complexity of natural language can be recast in dependency structure terms. It turns out that more than 99.5% of the structures in both the Prague Dependency Treebank (PDT) (Hajič et al., 2001) and Danish Dependency Treebank (DDT) (Kromann. 2003) are well-nested and gap degree ≤ 1 (Kuhlmann and Nivre, 2006). However, it is not obvious what to conclude regarding the gap degree and ill/well-nestedness of natural language from the small number of remaining data. While ill-nested structures have been assigned to some examples in the literature (Boston et al, 2009, Maier and Lichte, 2009), a closer look at these examples shows that reasonable alternative analyses result in structures that are no longer ill-nested. Specifically, when the auxiliary is assumed to be a dependent of the main verb instead of vice versa, the examples become well-nested. This precludes us from using these examples to make the kind of strong claim we would like to: that ill-nestedness is an unavoidable linguistic reality. Our first contribution is the articulation of two empirically verifiable questions of theoretical interest: Does natural language include structures that are unavoidably ill-nested and/or gap degree > 1? Our second contribution is the submission of two examples, a German construction that involves both extraposition and a split quantifier, and a Czech comparative, which we claim are unavoidably ill-nested. Based on these, we conclude that ill-nestedness is indeed unavoidable in natural language and grammars that generate only well-nested structures (such as LTAG) are not quite powerful enough.

Unlike LTAG, its Tree Local Multi-component extension (TL-MCTAG) does have the capacity to induce structures that are ill-nested (Kuhlmann and Möhl, 2006) and also to accommodate the two examples we present. This aligns well with what we know about TAG and TL-MCTAG in traditional terms: Although TL-MCTAGs are weakly equivalent to TAGs, they are more powerful than TAGs in terms of strong generative capacity, i.e., they permit the derivation of structures not derivable in TAGs, and thus have been argued to be a necessary extension to TAGs on linguistic grounds.

The paper is structured as follows. Section 2 reviews the notions of gap degree and well-/ill-nestedness. Section 3 uses LTAG to illustrate how a derivation of a generative grammar can be alternately represented as a dependency graph and reviews how the class of LTAG derivations corresponds to the class of well-nested and gap degree ≤ 1 dependency structures. Section 4 turns to linguistic data. We show how plausible alternate reanalyses can lead to well-nestedness for some previous examples, and discuss the two examples for which we argue that ill-nestedness is unavoidable. Section 5 shows how an analysis for our German example is available in the TL-MCTAG extension, which permits derivations associated with ill-nested dependency structures. Section 6 compares and contrasts dependency structures induced by TAGs with those induced by Combinatorial Categorial Grammars (Koller and Kuhlmann, 2009) and Minimalist Grammars (Boston et al, 2009). Section 7 summarizes and concludes the paper.

2 Discontinuity in Dependency Structures

The dependency structures we refer to in this paper are 3-tuples: a set of nodes, a dominance relation, and a (total) precedence relation. Dominance is encoded via a directed edge and precedence is encoded via left to right position on the page. Here, we review two measures of discontinuity defined on dependency structures. Expanded explanation can be found in (Kuhlmann and Nivre, 2006).

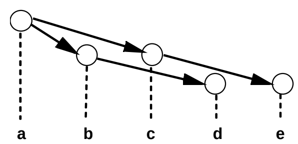

Figure 1. An example dependency structure

2.1 Gap Degree

It will be useful to first define the term *projection*.

Definition: The projection of a node x is the set of nodes dominated by x (including x).

Definition: A *gap* is a discontinuity with respect to precedence in the projection of a node in the dependency structure. (E.g. in Figure (1), the node *c* is the gap preventing *b* and *d* from forming a contiguous interval.)

Definition: The *gap degree of a node* is the number of gaps in its projection.

Definition: The *gap degree of a dependency structure* is the max among the gap degrees of its nodes.

2.2 Well-/Ill-nestedness

Definition: If the roots of two subtrees in the dependency structure are not in a dominance relation, then the trees are *disjoint*.

Definition: If nodes x_1, x_2 belong to tree X, nodes y_1, y_2 belong to tree Y, precedence orders these nodes: $x_1 > y_1 > x_2 > y_2$, and X and Y are disjoint, then trees X and Y *interleave*. (E.g, in Figure (1), *b* and *d* belong to the subtree rooted in *b*, while *c* and *e* belong to the subtree rooted in *c*. These two subtrees are disjoint. Since the nodes are ordered *b* > *c* > *d* > *e*, the two trees interleave.)

A dependency graph with interleaving subtrees is *ill-nested*, as in (1). A dependency graph with no interleaving is *well-nested*, (e.g Fig. (2d)).

3 LTAG Derivations as Dependency Structures

The LTAG induced dependency structures detailed by Bodirsky et al. (2005) provide an example of how a derivation of a generative grammar can be translated into a dependency graph, retaining information from both the derivation itself and its final phrase structure. We illustrate using a derivation based on the cross-serial dependencies seen in Dutch subordinate clauses, shown in Figure 2. (2a) shows a set of four LTAG elementary trees. (2c) is the derivation structure showing how these four trees combine to yield the derived phrase structure in (2b). (2d) shows the dependency structure that corresponds to this derivation.

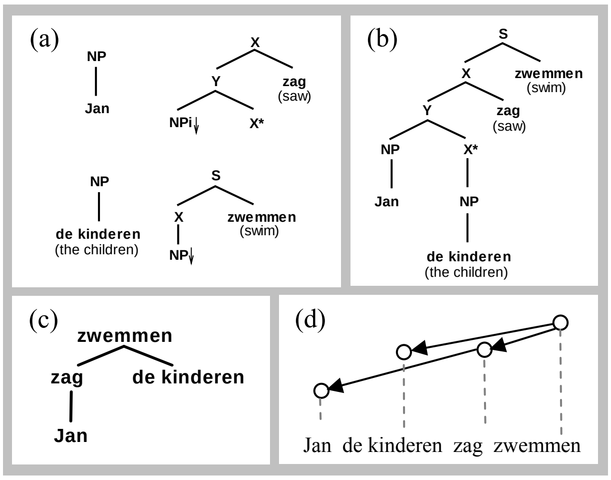

Figure 2. Grammar, phrase structure, and derivation for *Jan de kinderen zag zwemmen* and corresponding graph drawing

First, the set of nodes in the dependency structure corresponds to the set of lexical anchors of the elementary trees. For example, *Jan* anchors an NP tree in (2a). Thus, *Jan* will be a node label in any dependency structure induced by an LTAG derivation involving this tree. Second, the directed edges between the nodes in the dependency structure mirror the immediate dominance relation in the derivation tree.[1] E.g. Just as the *zwemmen* node has the *zag* and *de kinderen* nodes as its two children in (2c), so does the *zwemmen* node have *zag* and *de kinderen* as dependents in (2d). Lastly, the ordering of the nodes in the dependency structure is exactly the ordering of the terminals in the derived phrase structure.

3.1 The Source of Gaps in LTAG

In TAG-induced dependency structures, a gap arises from an interruption of the dependencies in an auxiliary tree. The lexical anchor of an auxiliary tree and the pronounced material that is combined into that tree will be part of the same projection in the induced dependency structure. Pronounced material below the foot of the auxiliary tree, however, will belong to the tree “hosting” the auxiliary tree, and will not be part of the same projection.[2] If Tree B is adjoined into Tree A, the gap is the material in A that is below the foot node of B. E.g. in the derivation in Figure 2, *de kinderen* is substituted into the *zwemmen* tree below the node into which the *zag* tree adjoins into the *zwemmen* tree. Thus, *de kinderen* interrupts the pronounced material on the left of the *zag* tree’s foot node, *Jan*, from the pronounced material on the right of the foot node, *zag*. Since standard TAG auxiliary trees have only one foot, each projection in a TAG-induced dependency structures can have at most one gap.

3.2 Well-nestedness in LTAG

LTAG-induced dependency structures are all well-nested. Recall that the sole source for gaps is pronounced material in the “host” tree below the foot of an auxiliary tree. Suppose an LTAG derivation did have a corresponding ill-nested dependency structure. I.e. suppose Tree A and Tree B are disjoint subtrees in the dependency structure, nodes from Tree A interrupt nodes from Tree B, and nodes from Tree B interrupt nodes from Tree A. If the nodes of Tree A interrupt the nodes of Tree B, this implies that in the derivation, Tree B is an aux-

[1] Whereas in standard dependency graphs, adjunction of t2 to t1 generally corresponds to a dependency directed from t2 to t1, in a TAG-induced dependency graph, adjoining t2 to t1 corresponds to the reverse dependency.

[2] Since each node of an LTAG-induced dependency structure is associated with the lexical anchor of an LTAG tree, we have assumed dependency structure nodes to be associated only with pronounced material.

iliary tree that adjoins into Tree A. However, if the nodes of Tree B likewise interrupt the nodes of Tree A, this implies that Tree A is also an auxiliary tree and that it adjoins into Tree B. It is not possible that an LTAG derivation should include Tree A and Tree B adjoining into one another.

4 Linguistic Examples of Ill-nestedness

4.1 Nestedness and Alternative Analyses

It is clear that a linguistic example that requires ill-nestedness will involve at least two discontinuous constituents. However, this is a necessary condition, not a sufficient one. Apparent ill-nestedness can sometimes be avoided via a plausible alternate reanalysis. For example, a number of ill-nested German examples from a dependency version of the TIGER (a phrase structure based treebank to which a conversion algorithm has been applied) are ill-nested only when the auxiliary is assumed to be the root and the main verb and subject are daughters of the auxiliary. When the main verb is assumed to be the root instead, and the subject and auxiliary verb are assumed to be dependents of the main verb, the dependency structure becomes well-nested.[3] This is the case with examples in Maier and Lichte (2009) (examples from converted dependency treebanks) and also the double extraposition example in English in Boston et al (2009) (authors' original example). Because the ill-nestedness depends on choosing the auxiliary verb as the root, we cannot use these examples to make the kind of strong claim we would like to: that ill-nestedness is an unavoidable linguistic reality.

4.2 Ill-nestedness in German

Our example from German involves two discontinuities, extraposition from an NP and a split quantifier. In example (1b) below, the relative clause *der am meisten Geld hatt* 'who had the most money' has been extraposed away from the NP *der Student* 'the student,' and the NP *Bücher* 'books' is separated from its quantifier *drei* 'three.' The canonical order is given in (1a).[4]

(1) a. [*Der Student* [*der am meisten Geld*
 the student, who the most money
 hatte]] *hat* [*drei* [*Bücher*]] *gekauft*.
 had has three books bought
 b. Bücher hat DER Student drei gekauft,
 Books has that student three bought
 der am MEIsten Geld hatte.
 who the most money had

The ill-nested part of the structure involves the sub-structures rooted in *Bücher* 'books' and *hatte* 'had.' Note that these two root nodes are not in any dominance relation and are therefore disjoint. The projection of the former includes *Bücher* and *drei* 'three.' The projection of the latter includes *der Student*, *der*, *am moisten Geld*, and *hatte*. As the figure shows, the projection of *Bücher* is interrupted by *der Student*, and the projection of *hatte* is interrupted by *drei*.

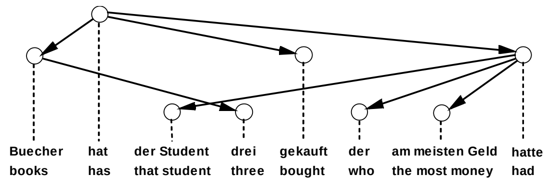

Figure 3. Dependency structure 1 for (1b): aux dominates main verb

Interestingly, this German construction remains ill-nested when we suppose instead that the main verb is the root, reversing the dependency between the main verb and the auxiliary. As can be seen in the dependency structure in Fig. 4, the ill-nested substructures are unaffected. This alternate analysis lends itself well to a TAG based analysis, which would typically assume the main verb to be the root (allowing verbs and substitution nodes for their arguments to be elementary tree local).

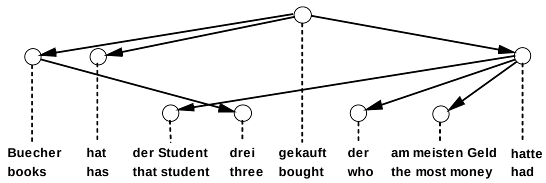

Figure 4. Dependency structure 2 for (1b): main verb dominates aux

[3] Thanks to Marco Kuhlmann for making the TIGER examples available and to Tatjana Scheffler for this observation.

[4] Appropriate context and intonation will, of course, make this reading easier. The example has contrastive stress and a contrastive reading and is felicitous in a context such as the one below. Tatjana Scheffler is gratefully acknowledged for providing this example and context.

A: Every student bought multiple items in the store. Some bought three magazines, some bought two calendars, some bought two books, and the oldest student bought three books.
B: No, hat DER Student drei gekauft, der am meisten Geld hatte.

4.3 Ill-nestedness in Czech

Boston et al. (2009) note that ill-nested structures have been assigned to Czech comparatives. Their example, sentence number Ln94209_45.a/18 from the PDT 2.0, can be glossed as "A strong individual will obviously withstand a high risk better than a weak individual" and is given in Fig. 5. It is of particular interest because, like our German example, the ill-nestedness here involves two constituents between which it would be difficult to justify a dependency. This suggests that the substructures corresponding to the two constituents will remain disjoint under reasonable analyses, and thus, the dependency structures will remain ill-nested.

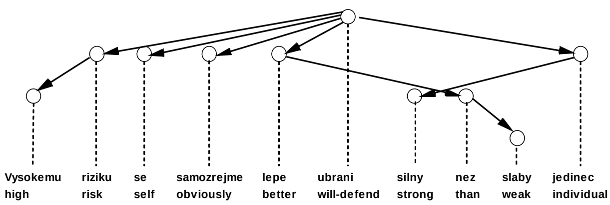

Figure 5. Ill-nested Czech comparative from PDT[5]

5 TL-MCTAG Induced Dependency Structures

MCTAG (Weir 1988) is one of the most widely used extensions for handling linguistic cases that are difficult for classic TAG. Whereas TAG takes the basic unit to be a single elementary tree, MCTAGs extend the domain of locality to encompass a set of trees. The tree-local MC-extension, in which all members of an multi-component set must combine into the same "host" tree, allows for linguistically satisfying accounts for a number of attested phenomena, such as: English extraposition (Kroch and Joshi 1990), subj-aux inversion in combination with raising verbs (Frank 2002), anaphoric binding (Ryant and Scheffler 2006), quantifier scope ambiguity (Joshi et al. 2003).

We have assumed here that each MC-set is lexicalized and that the set of nodes in MCTAG-induced dependency structures corresponds to the set of lexical anchors, just as we assumed for LTAG-induced dependency structures. Silent elements, such as traces, do not anchor an elementary tree, and so do not correspond to a node in the dependency structure. Kuhlmann and Möhl (2006) show that dependency structures induced from tree-local MCTAG derivations in this way include structures that are ill-nested and/or gap degree > 1.

5.1 Additional Source of Gaps in MC-TAGs

In 3.1, we noted that the source of every gap in an LTAG induced dependency structures is an interruption of the dependencies of an auxiliary tree. Thus, a MC-set comprised of two auxiliary trees allows the potential for at least two gaps in MCTAG induced dependency structures, one associated with each foot. There is a second source of gaps in MCTAG: a gap may arise as a result of any pronounced material between two components. Thus, the maximum gap degree = $2n - 1$, where n is the maximum number of components in any elementary tree set.

5.2 Ill-nestedness in MC-TAG

Because material between the nodes where two components of a MC-set compose into a host tree can also create a gap, even a tree-local MCTAG that allows only substitution can induce an ill-nested dependency structure. Ill-nestedness arises when two MC-sets combine into the same host tree and the nodes into which each set combines interleave. This will be illustrated below by the TL-MCTAG derivation for our German example.

5.3 The Adequacy of TL-MCTAG

The MC-TAG derivation for (1b) will require a tree headed by *gekauft* 'bought' (shown in 6h) into which two MC-sets combine, one for *Bücher* 'books' and its trace (shown in 6b) and a second for *hatte* (and the rest of the relative clause) and its trace (shown in 6a). The singleton sets involved are also shown in Fig 6c-6h. To derive (1b), *drei* (6f) adjoins into the β component of (6b), which substitutes into the lower NP of the *gekauft* tree, (6h). The α component of (6b) adjoins to the root of (6h). To accomplish extraposition, we make use of *flexible composition*, the mirror operation of adjoining: If tree A adjoins into tree B, the combination can be alternatively viewed as tree B "flexibly" composing with tree A (Joshi et al. 2003, Kallmeyer and Joshi 2003).[6]By enriching MCTAG

[5] The non-lexical root node and punctuation node are removed for simplicity. Thanks is due to Marisa Ferrara Boston for making this PDT structure available.

[6] A TL-MCTAG with flexible composition can also be viewed as an MCTAG allowing *delayed tree-locality* (Chiang and Scheffler, 2008).

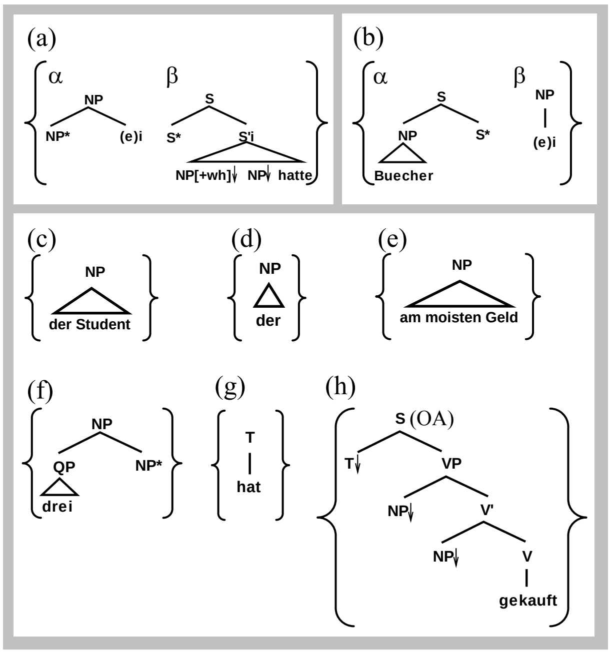

Figure 6. MC-set for extraposition of a relative clause, MC-set for split quantifier, and singleton sets for deriving example (1b)[7]

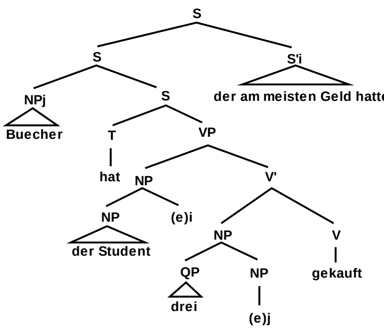

Figure 7. Phrase structure for example (1b)

with this perspective of adjoining, some derivational steps which appear to permit components from the same MC-set to combine into different-trees can be recast as abiding by tree-locality. *Der Student*, (6c), flexibly composes into the αcomponent of the set in (6a), while *der,* (6d), and *am meisten Geld,* (6e), substitute into the β component. The (derived) α component of (6a) adjoins into the highest NP node in (6h), while β, the extraposed relative, adjoins into the root of (6h). Additionally, (6g), the auxiliary verb, substitutes into the T node of (6h) the *gekauft* tree. This derivation yields the phrase structure in Fig. 7 and corresponds to the dependency structure in Fig. 4.We have not fully committed to the direction of the dependency for flexible composition. If flexible composition is to be truly viewed as an alternate conception of adjoining, then perhaps the direction of the dependency when A flexibly composes into B should be identical to that of the dependency when B adjoins into A. Whatever the outcome, the ill-nestedness of our German example remains, as can be seen in the alternate dependency structure in Fig. 8. The ill-nestedness involves the same nodes, but the roots of the disjoint substructures are now *Bücher* and *der Student*.[8]

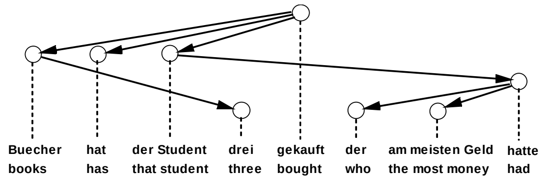

Figure 8. Dependency structure 3 for (1b): *Der student* governs *hatte*

6 Dependency Structures Across Generative Frameworks

6.1 CCGs and Dependency Structures

Koller and Kuhlmann (2009) show how derivations in (a fragment of) Combinatory Categorial Grammars (CCG) (Steedman, 2001) can be viewed as dependency structures. The source of gaps appears to correspond to alternating application of the CCG operations forward and backwards composition, making it difficult to state a bound on gap degree. As the authors show, it follows that TAG (which induces gap degree ≤ 1 structures) does not generate the same class of dependency structures as CCG. It is unclear, however, whether or not ill-nested structures are permitted.

6.2 MGs and Dependency Structures

Boston et al (2009) approach Minimalist Grammars (MG) (Stabler, 1997) from a dependency

[7] The V2 requirement in German can be handled with an *obligatory adjoining* constraint (denoted OA) on the S node of the tree for the main verb. The particular implementation of the V2 requirement is not relevant to our main argument. See (Kinyon et. al. 2006) for a TAG approach to V2.

[8] Thus, there is some room to accommodate Candito and Kahane's (1998) arguments that the direction of the dependency for adjoining is the reverse of that for substitution. Note further that in the MCTAG case, a non-uniform interpretation of derivation tree arcs raises the issue of the direction of the dependency in the case where one component adjoins into a host tree while a second component combines via substitution.

structure perspective, showing that ill-nested structures are derivable and showing how gaps arise. In MG induced dependency structures, every gap is associated with movement (although not every movement corresponds to a gap). In MGs, every movement involves a liscensor and licensee pair, both of which are lexical entries. At first blush, it appears that the unlimited number of movements (i.e. uses of these entries) permitted during an MG derivation also permits an unbounded number of gaps. It turns out, however, that the gap degree for the class of dependency structures associated with a particular MG is bound by the number of licensees in that MG's lexicon due to two linguistic considerations. First, each licensee features depends on a linguistically motivated functional category. Thus, the number of features permitting movement is finite. Second, the ShortestMovementConstraint, which has been incorporated into the MG definition, prohibits subsequent uses of the same licensee feature from interacting with the first use. The subderivations are, in the relevant sense, independent, generating substructures whose gap degree is bound by the number of licensee features. The result is that even as an MG derivation grows, the gap degree does not increase beyond the number of licensee features. (Boston, Hale, p.c.)

6.3 Comparison with TL-MCTAG

The most obvious difference across formalisms is the source of gaps and, consequently, the ease with which a bound on gap degree can be stated. For TL-MCTAG, a bound is straightforwardly stated via the maximum number of components permitted in an elementary set. Though TL-MCTAG as a formal system allows any number of components in an MC-set, TL-MCTAG as used in linguistic analyses typically uses only two components (Chen-Main and Joshi, 2007). In a sense, TL-MCTAG with two components arises naturally from standard TAG, particularly when adjoining is viewed as reversible. In the case where tree A adjoins into a tree internal node *x* in B, reversing the composition can be recast as follows: B is split into a two-component set at node *x* with one component adjoining into the root of tree A and the second component substituting into the foot of A. Motivating three-component sets is more difficult.

A question that remains is whether or not there constructions that are unavoidably gap degree 2 or more. We are aware of one gap degree 2 example from a Hindi dependency treebank that is being developed with the annotation scheme detailed in (Begum et al, 2008) (Mannem, p.c.), though we have not yet investigated whether other plausible analyses will retain the gap degree 2 property.

7 Summary

This paper raises the question of whether or not natural language includes structures that are unavoidably ill-nested and/or gap degree > 1, and motivates this issue as part of understanding the complexity of natural language in dependency structure terms. Based on one German linguistic example and one Czech example from the PDT, we conclude that the answer to the first question is affirmative and that a grammar formalism on the right track for characterizing human language should be able to induce ill-nested structures. TL-MCTAG's ability to cover ill-nested structures bolsters its candidacy as a good model of natural language, but, as yet, it is unclear whether its ability to also induce dependency structures that are gap degree > 1 is linguistically useful or not. The next step is to find examples that are unavoidably gap degree >1.

These issues are relevant not only for TL-MCTAG but also for other generative approaches that induce ill-nested, gap degree > 1 dependency structures, such as Minimalist Grammars (Boston et. al. 2009). Moreover, we predict that other formalisms which are equivalent in traditional terms will also induce such structures, mirroring the convergence noted in (Joshi et al., 1991). However, because these formalisms employ different formal objects and operations, we also expect more nuanced differences, such as the source of gaps, or the ease with which one can state a bound on gap degree in each framework.

Acknowledgments

Special thanks is due to Marisa Ferrara Boston, Lucas Champollion, John Hale, Marco Kuhlmann, Prashanth Mannem, Beatrice Santorini, and Tatjana Scheffler for helpful discussion and especially assistance with data.

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