Separating Dependency from Constituency in a Tree Rewriting System*

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1 Introduction

We define a new grammar formalism called Link-Sharing Tree Adjoining Grammar (LSTAG) which arises directly out of a concern for distinguishing the notion of constituency from the notion of relating lexical items in terms of linguistic dependency (Mel'čuk, 1988; Rambow and Joshi, 1992). This work derives directly from work on Tree Adjoining Grammars (TAG) (Joshi, Levy, and Takahashi, 1975) where these two notions are conflated. The set of derived trees for a TAG correspond to the traditional notions of constituency while the derivation trees of a TAG are closely related to dependency structure (Rambow and Joshi, 1992). A salient feature of TAG is the extended domain of locality it provides for stating these dependencies. Each elementary tree can be associated with a lexical item giving us a lexicalized TAG (LTAG) (Joshi and Schabes, 1991). Properties related to the lexical item such as subcategorization, agreement, and certain types of word-order variation can be expressed directly in the elementary tree (Kroch, 1987; Frank, 1992). Thus, in an LTAG all of these linguistic dependencies are expressed locally in the elementary trees of the grammar. This means that the predicate and its arguments are always topologically situated in the same elementary tree.

However, in coordination of predicates, e.g. (1), the dependencies between predicate and argument cannot be represented in a TAG elementary tree directly, since several elementary trees seem to be ‘sharing’ their arguments.

(1) a. Kiki frolics, sings and plays all day.
   b. Kiki likes and Bill thinks Janet likes soccer.

The idea behind LSTAG is that the non-local nature of coordination as in (1) (for TAG-like grammar formalisms) can be captured by introducing a restricted degree of synchronized parallelism into the TAG rewriting system while retaining the existing independent parallelism (Engelfriet, Rozenberg, and Slutzki, 1980; Rambow and Satta, to appear). We believe that an approach towards coordination that explicitly distinguishes the dependencies from the constituency gives a better formal understanding of its representation when compared to previous approaches that use tree-rewriting systems which conflate the two issues, as in (Joshi, 1990; Joshi and Schabes, 1991; Sarkar and Joshi, 1996) which have

*Thanks to Christy Doran, Aravind Joshi, Nobo Komagata, Owen Rambow, and B. Srinivas for their helpful comments and discussion.

The term dependency is used here broadly to include formal relationships such as case and agreement and other relationships such as filler-gap.

2It is important to note that while the adjunction operation in TAGs is “context-free”, synchronized parallelism could be attributed to the TAG formalism due to the string wrapping capabilities of adjunction, since synchronized parallelism is concerned with how strings are derived in a rewriting system. We note this as a conjecture but will not attempt to prove it here.
to represent sentences such as [1] with either un-rooted trees or by performing structure merging on the derived tree. Other formalisms for coordination have similar motivations: however their approaches differ, e.g. CCG [Steedman, 1985; Steedman, 1997b] extends the notion of constituency, while generative syntacists [Moltmann, 1992; Muadz, 1991] work with three-dimensional syntactic trees.

2 Synchronized Parallelism

The terms synchronized parallelism and independent parallelism arise from work done on a family of formalisms termed parallel rewriting systems that extend context-free grammars (CFG) by the addition of various restrictive devices (see [Engelfriet, Rozenberg, and Slutzki, 1980]). Synchronized parallelism allows derivations which include substrings which have been generated by a common (or shared) underlying derivation process. Independent parallelism corresponds to the instantiations of independent derivation processes which are then combined to give the entire derivation of a string. What we are exploring in this paper is an example of a mixed system with both independent and synchronous parallelism.

In [Rambow and Satta, to appear] it is shown that by allowing an unbounded degree of synchronized parallelism we get systems that are too unconstrained. However, interesting subfamilies arise when the synchronous parallelism is bounded to a finite degree, i.e. only a bounded number of subderivations can be synchronized in a given grammar. The system we define has this property.

3 LSTAG

We first look at the formalism of Synchronous TAG (STAG) [Shieber and Schabes, 1991] since it is an example of a tree-rewriting system that has synchronized parallelism.

As a preliminary we first informally define Tree Adjoining Grammars (TAG). For example, Figure 4 shows an example of a tree for a transitive verb cooked. Each node in the tree has a unique address obtained by applying a Gorn tree addressing scheme. For instance, the object NP has address 2.2. In the TAG formalism, trees can be composed using the two operations of substitution (corresponds to string concatenation) and adjunction (corresponds to string wrapping). A history of these operations on elementary trees in the form of a derivation tree can be used to reconstruct the derivation of a string recognized by a TAG. Figure 2 shows an example of a derivation tree and the corresponding parse tree for the derived structure obtained when α(John) and α(beans) substitute into α(cooked) and β(dried) adjoins into α(beans) giving us a derivation tree for John cooked dried beans. Trees that adjoin are termed as auxiliary trees, trees that are not auxiliary are called initial. Each node in the derivation tree is the name of an elementary tree. The labels on the edges denote the address in the parent node where a substitution or adjunction has occurred.

Definition 1 In a TAG \( G = \{ \gamma \mid \gamma \) is either an initial tree or an auxiliary tree \}, we will notate adjunction (similarly substitution) of trees \( \gamma_1 \ldots \gamma_k \) into tree \( \gamma \) at addresses \( a_1 \ldots a_k \) giving a derived tree \( \gamma' \) as

\[ \gamma' = [a_1, \gamma_1] \ldots [a_k, \gamma_k] \]

Definition 2 Given two standard TAGs \( G_L \) and \( G_R \) we define (from [Shieber, 1994]) a STAG as \( \{ \gamma, \gamma', \sim \mid \gamma \in G_L, \gamma' \in G_R \} \), where \( \sim \) is a set of links from a node address in \( \gamma \) to a node address in \( \gamma' \). A derivation proceeds as follows:

- for \( \gamma = \langle \gamma_L, \gamma_R, \sim \rangle \), pick a link member \( a_L \sim_i \) \( a_R \), where the a’s are node addresses and \( \sim_i \in \sim \). For simplicity, we refer to \( \sim \) as link and its elements \( \sim_i \) as link members.

- adjunction (similarly substitution) of \( \langle \beta_L, \beta_R, \sim' \rangle \) into \( \gamma \) is given by

\[ \langle \gamma_L, \gamma', \sim'' \rangle = \langle \gamma_L[a_L, \beta_L], \gamma'R[a_R, \beta_R], \sim'' \rangle \]

3 The Lindenmayer systems are examples of systems with only synchronous parallelism and it is interesting to note that these systems have the anti-AFL property (where none of the standard closures apply).
4 CFG is a formalism that only has independent parallelism.
where all links in $\sim$ and $\sim'$ are included in $\sim''$ except $\sim_i$.

- $\langle \gamma'_L, \gamma'_R, \sim'' \rangle$ is now a derived structure which can be further operated upon.

In (Abeillé, 1992; Abeillé, 1994) STAGs have been used in handling non-local dependencies and to separate syntactic attachment from semantic roles. However, STAG cannot be used to separate the dependencies created in (pairs of) derivation trees for coordinate structures from the constituency represented in these derivation trees. In this particular sense, STAG has the same shortcomings as defined in Defn 2. We call this formalism Link-Sharing TAG (LSTAG).

**Definition 3** An LSTAG $G$ is defined as a 4-tuple $(G_L, G_R, \Delta, \Phi)$ where $G_L, G_R$ are standard TAGs, $\Delta$ and $\Phi$ are disjoint sets of sets of links and for each pair $\gamma = \langle \gamma_L, \gamma_R \rangle$, where $\gamma_L \in G_L$ and $\gamma_R \in G_R$, $\delta_\gamma \in \Delta$ is a subset of links in $\gamma$ and $\phi_{\gamma_R} \in \Phi$ is a distinguished subset of links with the following properties:

- for each link $\sim \in \phi_{\gamma_R}$, $\eta \sim \eta$, where $\eta$ is a node address in $\gamma_R$, i.e. $\phi_{\gamma_R}$ is a set of reflexive links.
- $\delta_R$ and $\phi_{\gamma_R}$ have some canonical order $\prec$.
- adjunction (similarly substitution) of $\langle \beta_L, \beta_R \rangle$ into $\gamma$ is given by
  \[
  \langle \gamma'_L, \gamma'_R \rangle = \langle \gamma_L[a_L, \beta_L], \gamma_R[a_R, \beta_R] \rangle
  \]
  and for all $\gamma_i \in \delta_\gamma, \beta_i \in \phi_{\beta_R}(1 \leq i \leq n)$ (card$(\delta_\gamma) \geq$ card$(\beta_R)$)
  \[
  \delta_\gamma \cup \phi_{\beta_R} \overset{def}{=} \sim_{\gamma_1} \cup \sim_{\beta_1} \cup \ldots \cup \sim_{\gamma_n} \cup \sim_{\beta_n}
  \]

![Figure 1: Example of a TAG](image1)

![Figure 2: Example of a derivation tree and corresponding parse tree](image2)
where
\[ \gamma_1 \prec \gamma_2 \prec \cdots \prec \gamma_n \]
and
\[ \beta_1 \prec \beta_2 \prec \cdots \prec \beta_n \]

- \( \gamma_i \cup \gamma_j \) is a set of links defined as follows. If \( a_{L_i} \prec a_{R_i} \) and \( a_{R_j} \prec a_{R_j} \), then
  \[ \gamma_i \cup \gamma_j \overset{def}{=} \{ a_{L_i} \prec a_{R_i} \} \cup \{ a_{L_j} \prec a_{R_j} \} \]

- \( \langle \gamma_L, \gamma_R \rangle \) is the new derived structure with new set of links \( \delta_G \cup \beta_R \).

\( \Phi \) is used to derive synchronized parallelism in \( G_R \). The ordering \( \prec \) is simply used to match up the links being shared via the (non-local) sharing operation \( \cup \).

This ordering \( \prec \) can be defined in terms of node addresses or “first argument \( \prec \) second argument”, i.e. ordering the arguments of the two predicates being coordinated.

It is important to note that only the links in \( \Phi \) are used non-locally and they are always exhausted in a single adjunction (or substitution) operation. No links from \( \Delta \) are ever inherited unlike STAGs. Hence, non-locality is only used in a restricted fashion for the notion of 'sharing'.

4 Linguistic Relevance

To explain how the formalism works consider sentence (2).

(2) John cooks and eats beans.

Consider a LSTAG \( G = \{ \gamma, \beta, \alpha, v \} \) partially shown in Fig. 3(a) and Fig. 3(b). \( \alpha \) and \( v \) are analogously defined for \( \text{John} \) and \( \text{beans} \) respectively (see Fig. 4). In Fig. 3(a) \( \delta_\gamma = \{ 1, 2 \} \) and \( \phi_{\gamma_R} = \{ \} \), while for Fig. 3(b) \( \delta_\gamma = \{ \} \) and \( \phi_{\gamma_R} = \{ 1, 2 \} \).

It is important to note that our initial motivation about separating dependency from the constituency information is highlighted in \( \beta \) (see Fig. 3(b)) where the first projection will only contribute information about constituency in a derivation tree while the second projection will contribute only dependency information in a derivation tree. We conjecture that this is true for all the structures defined in an LSTAG, the kind of questions addressed in (Rambow, Vijay-Shanker, and Weir, 1995) can perhaps be answered within the framework of LSTAG.

The derived structure after \( \beta \) adjoins onto \( \gamma \) is shown in Fig. 3(a). Fig. 3(a) shows the derived tree after the tree \( \alpha \) (for \( \text{John} \)) substitutes into \( \gamma \). Notice that due to link sharing, substitution is shared, effectively forming a “tangled” derived tree.

\[ (a) \gamma : \begin{cases} \text{NP}_{11} \rightarrow \text{VP} \\ \text{V} \rightarrow \text{NP}_{11} \end{cases} \]

\[ (b) \beta : \begin{cases} \text{NP}_{12} \rightarrow \text{VP} \\ \text{V} \rightarrow \text{NP}_{12} \end{cases} \]

Figure 3: Trees \( \gamma \) and \( \beta \) from LSTAG

\[ 5 \] We are just using numbers 1, 2, … to denote the links rather than use the Gorn notation to make the trees easier to read. Here, link number 1 stands for \( 1 \prec 1 \) and 2 stands for \( 2 \prec 2 \).

\[ 6 \] In (Rambow, Vijay-Shanker, and Weir, 1995) a new formalism called D-Tree Grammars was introduced in order to bring together the notion of derivation tree in a TAG with the notion of dependency grammar (Mel'čuk, 1985). Perhaps the kind of questions addressed in (Rambow, Vijay-Shanker, and Weir, 1995) can also be handled using the current framework. Such an application of the formalism would motivate the need for trees like \( \gamma \) in Fig. 3 independent of the coordination facts since they would be required to get the dependencies right.

\[ 7 \] While this notion of sharing bears some resemblance to the notion of sharing node in the three-dimensional trees used in (Moltmann, 1992; Muñoz, 1991) the rules for semantic interpretation of the derivations produced in a LSTAG is con-
and the derivation trees are also given (associated with each element). The derivation structure for the second element in Fig. 5(b) is a directed acyclic derivation graph which gives us information about dependency we expect. The derivation tree of the first element in Fig. 5(b), on the other hand, gives us information about constituency.

The notion of link sharing is closely related to the schematization of the coordination rule in (Steedman, 1997b) shown below in combinatory notation.

\[
\begin{align*}
    bxy &\equiv bxy \\
    bf g &\equiv \lambda x.b(fx)(gx) \\
    bg f &\equiv \lambda x.\lambda y.b(fxy)(gxy) \\
    \ldots
\end{align*}
\]

Link sharing is used to combine the interpretation of the predicate arguments \(f\) and \(g\) (e.g. *cooks, eats*) of the conjunction \(b\) with the interpretation of the arguments of those predicates \(x, y, \ldots\). However, it does this within a tree-rewriting system, unlike the use of combinators in (Steedman, 1997b).

5 Restrictions

Having defined the formalism of LSTAG, we now define certain restrictions on the grammar that can be written in this formalism in order to capture correctly certain facts about coordinate structures in English.

For instance, we need to prohibit elementary structures like the one in Fig. 6 because they give rise to ungrammatical sentences like (3).

(3) *Peanuts John likes and almonds hates. (Joshi, 1990)

However, such restrictions in the context of TAGs have been discussed before. (Joshi, 1990) rules out (3) by stating a requirement on the lexical string spelled out by the elementary tree. If the lexical string spelled out is not contiguous then it cannot coordinate. This requirement is stated to be a phonological condition and relates the notion of an intonational phrase (IP) to the notion of appropriate fragments for coordination (in the spirit of (Steedman, 1997b)). It is important to note that the notions of phrase structure for coordination and intonational phrases defined in (Joshi, 1990) for TAG are not identical, whereas they are identical for CCG (Steedman, 1997a).

We can state an analogous restriction on the formation of elementary structures in a LSTAG, one that is motivated by the notion of link sharing. The left element of an elementary structure in a LSTAG cannot be composed of discontinuous parts of the right element. For example, in Fig. 6 the segment \([s][vP][vP]\) from the right element has been excised in the left element. This restriction corresponds to the notion that the left element of a structure in a LSTAG represents constituency.

6 Conclusion

We have presented a new tree-rewriting formalism called Link-Sharing Tree Adjoining Grammar (LSTAG) which is a variant of synchronous TAGs (STAG). Using LSTAG we defined an approach towards coordination where linguistic dependency is distinguished from the notion of constituency. Appropriate restrictions on the nature of elementary structures in a LSTAG were also defined. Such an approach towards coordination that explicitly distinguishes dependencies from constituency gives a better formal understanding of its representation when compared to previous approaches that use tree-rewriting systems which conflate the two issues (see (Joshi and Schabes, 1991; Sarkar and Joshi, 1996)). The previous approaches had to represent coordinate structures either with unrooted trees or by performing structure merging on the parse tree. Moreover, the linguistic analyses presented in (Joshi and Schabes, 1991; Sarkar and Joshi, 1996) can be easily adopted in the current formalism.
Figure 4: Derived and derivation structures after $\beta$ adjoins into $\gamma$.

Figure 5: Substitution of $\alpha$

Figure 6: Discontiguous elementary structure
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