

# Coordination in Tree Adjoining Grammars: Formalization and Implementation\*

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## Abstract

In this paper we show that an account for coordination can be constructed using the derivation structures in a lexicalized Tree Adjoining Grammar (LTAG). We present a notion of derivation in LTAGs that preserves the notion of fixed constituency in the LTAG lexicon while providing the flexibility needed for coordination phenomena. We also discuss the construction of a practical parser for LTAGs that can handle coordination including cases of non-constituent coordination.

## 1 Introduction

Lexicalized Tree Adjoining Grammars (LTAG) and Combinatory Categorical Grammar (CCG) (Steedman, 1997) are known to be weakly equivalent but not strongly equivalent. Coordination schema have a natural description in CCG, while these schema have no natural equivalent in a standard LTAG.

In (Joshi and Schabes, 1991) it was shown that in principle it is possible to construct a CCG-like account for coordination in the framework of LTAGs, but there was no clear notion of what the derivation structure would look like. In this paper, continuing the work of (Joshi and Schabes, 1991), we show that an account for coordination can be constructed using the derivation structures in an LTAG.

Using the notions given in this paper we also discuss the construction of practical parser for LTAGs that can handle coordination including cases of non-constituent coordination. This approach has been implemented in the XTAG system (XTAG Research Group, 1995) thus extend-

ing it to handle coordination. This is the first full implementation of coordination in the LTAG framework.

## 2 LTAG

An LTAG is a set of trees (*elementary trees*) which have at least one terminal symbol on its frontier called the *anchor*. Each node in the tree has a unique address obtained by applying a Gorn tree addressing scheme, shown in the tree  $\alpha(\text{cooked})$  (Fig. 1). Trees can be rewritten using *substitution* and *adjunction*. 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 LTAG. In Fig. 1, the tree  $\beta(\text{dried})$  adjoins into  $\alpha(\text{beans})$  and trees  $\alpha(\text{John})$  and  $\alpha(\text{beans})$  substitutes into  $\alpha(\text{cooked})$  to give a derivation tree for *John cooked dried beans*. 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.

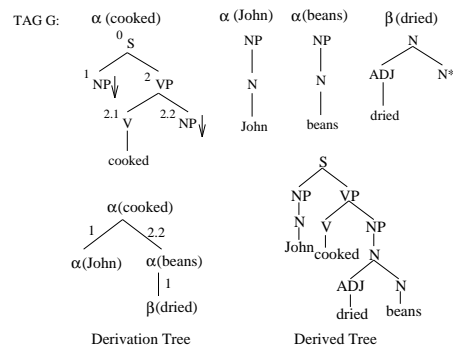


Figure 1: Example of an LTAG and an LTAG derivation

## 3 Trees as Structured Categories

In (Joshi and Schabes, 1991) elementary trees as well as derived trees in an LTAG were considered as structured categories defined as a 3-tuple of an elementary or derived tree, the string it spanned

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and the functional type of the tree, e.g.  $\langle \sigma_1, l_1, \tau_1 \rangle$  in Fig. 2. Functional types for trees could be thought of as defining un-Curried functions corresponding to the Curried CCG counterpart. A functional type was given to sequences of lexical items in trees even when they were not contiguous; i.e. discontinuous constituents were also assigned types. They were, however, barred from coordinating.

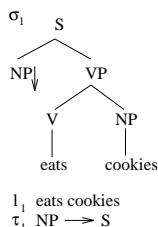


Figure 2: Structured Category for *eats cookies*

Coordination of two structured categories  $\sigma_1, \sigma_2$  succeeded if the lexical strings of both categories were contiguous, the functional types were identical, and the least nodes dominating the strings spanned by the component tree have the same label. For example, in Fig. 3 the tree corresponding to *eats cookies and drinks beer* would be obtained by:

1. equating the *NP* nodes<sup>1</sup> in  $\sigma_1$  and  $\sigma_2$ , preserving the linear precedence of the arguments.
2. coordinating the *VP* nodes, which are the least nodes dominating the two contiguous strings.
3. collapsing the supertrees above the *VP* node.
4. selecting the leftmost *NP* as the lexical site for the argument, since precedence with the verb is maintained by this choice.

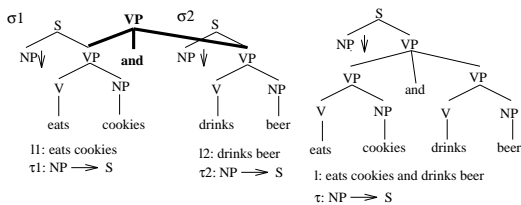


Figure 3: Coordination of *eats cookies and drinks beer*

The process of coordination built a new derived structure given previously built pieces of

<sup>1</sup>This notion of sharing should not be confused with a deletion type analysis of coordination. The scheme presented in (Joshi and Schabes, 1991) as well as the analysis presented in this paper are not deletion analyses.

derived structure (or perhaps elementary structures). There is no clear notion of a derivation structure for this process.

## 4 Coordination in TAG

An account for coordination in a standard LTAG cannot be given without introducing a notion of sharing of arguments in the two lexically anchored trees because of the notion of *locality* of arguments in LTAG. In (1) for instance, the NP *the beans* in the “right node raising” construction has to be shared by the two elementary trees (anchored by *cooked* and *ate* respectively).

- (1) (((Harry cooked) and (Mary ate)) the beans)

We introduce a notation that will enable us to talk about this more formally. In Fig. 1 the notation  $\downarrow$  denotes that a node is a non-terminal and hence expects a substitution operation to occur. The notation  $*$  marks the foot node of an auxiliary tree. Making this explicit we can view an elementary tree as a ordered pair of the tree structure and a ordered set<sup>2</sup> of such nodes from its frontier<sup>3</sup>, e.g. the tree for *cooked* will be represented as  $\langle \alpha(\textit{cooked}), \{1, 2.2\} \rangle$ . Note that this representation is not required by the LTAG formalism. The second projection of this ordered pair is used here for ease of explication. Let the second projection of the pair minus the foot nodes be the *substitution set*. We will occasionally use the first projection of the elementary tree to refer to the ordered pair.

*Setting up Contractions.* We introduce an operation called *build-contraction* that takes an elementary tree, places a subset from its second projection into a *contraction set* and assigns the difference of the set in the second projection of the original elementary tree and the contraction set to the second projection of the new elementary tree. The contents of the contraction set of a tree can be inferred from the contents of the set in the second projection of the elementary tree. Hence, while we refer to the contraction set of an elementary tree, it does not have to be stored along with its representation.

Fig. 4 gives some examples; each node in the contraction set is circled in the figure. In the tree  $\langle \alpha(\textit{cooked}), \{1, 2.2\} \rangle$  application of the operation on the *NP* node at address 2.2 gives us a tree with the contraction set  $\{2.2\}$ . The new tree is denoted by  $\langle \alpha(\textit{cooked})_{\{2.2\}}, \{1\} \rangle$ , or  $\alpha(\textit{cooked})_{\{2.2\}}$  for short. Placing the *NP* nodes at addresses 1 and 2.2 of the tree  $\alpha(\textit{cooked})$  into the contraction set gives us  $\alpha(\textit{cooked})_{\{1, 2.2\}}$ .

<sup>2</sup>The ordering is given by the fact that the elements of the set are Gorn addresses.

<sup>3</sup>We shall assume there are no adjunction constraints in this paper.

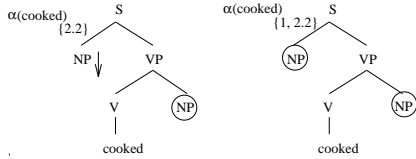


Figure 4: Building contraction sets

We assume that the anchor cannot be involved in a *build-contraction*. This assumption needs to be revised when gapping is considered in this framework (§5).

*The Coordination Schema.* We use the standard notion of coordination shown in Fig. 5 which maps two constituents of *like type*, but with different interpretations, into a constituent of the same type<sup>4</sup>.

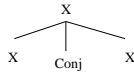


Figure 5: Coordination schema

We add a new rewriting operation to the LTAG formalism called *conjoin*<sup>5</sup>. While substitution and adjunction take two trees to give a derived tree, *conjoin* takes three trees and composes them to give a derived tree. One of the trees is always the tree obtained by specializing the schema in Fig. 5 for a particular category<sup>6</sup>.

Informally, the conjoin operation works as follows: The two trees being coordinated are substituted into the conjunction tree. This notion of substitution differs from the traditional LTAG substitution operation in the following way: In LTAG substitution, always the root node of the tree being substituted is identified with the substitution site. In the conjoin operation however, the node substituting into the conjunction tree is given by an algorithm, which we shall call *FindRoot* that takes into account the contraction sets of the two trees. *FindRoot* returns the lowest node that dominates all nodes in the substitution set of the elementary tree<sup>7</sup>, e.g.  $FindRoot(\alpha(cooked)_{\{2,2\}})$  will return the root node, i.e. corresponding to the *S*

<sup>4</sup>In this paper, we do not consider coordination of unlike categories, e.g. *Pat is a Republican and proud of it*. (Sarkar and Joshi, 1996) discusses such cases, following Jorgensen and Abeillé (1992).

<sup>5</sup>Later we will discuss an alternative which replaces this operation by the traditional operations of substitution and adjunction.

<sup>6</sup>The tree obtained will be a lexicalized tree, with the lexical anchor as the conjunction: *and*, *but*, etc.

<sup>7</sup>This ensures the node picked by *FindRoot* always dominates a contiguous string in a derivation. This captures the string contiguity condition that was used

*conj S* instantiation of the coordination schema.  $FindRoot(\alpha(cooked)_{\{1,2,2\}})$  will return node address 2.1, corresponding to the *V conj V* instantiation.

The conjoin operation then creates a *contraction* between nodes in the contraction sets of the trees being coordinated. The term *contraction* is taken from the graph-theoretic notion of edge contraction. In a graph, when an edge joining two vertices is contracted, the nodes are merged and the new vertex retains edges to the union of the neighbors of the merged vertices<sup>8</sup>. The conjoin operation supplies a new edge between each corresponding node in the contraction set and then contracts that edge. As a constraint on the application of the conjoin operation, the contraction sets of the two trees must be identical.

Another way of viewing the conjoin operation is as the construction of an auxiliary structure from an elementary tree. For example, from the elementary tree  $\langle\alpha(drinks), \{1, 2, 2\}\rangle$ , the conjoin operation would create the auxiliary structure  $\langle\beta(drinks)_{\{1\}}, \{2, 2\}\rangle$  shown in Fig. 6. The adjunction operation would now be responsible for creating contractions between nodes in the contraction sets of the two trees supplied to it. Such an approach is attractive for two reasons. First, it uses only the traditional operations of substitution and adjunction. Secondly, it treats *conj X* as a kind of “modifier” on the left conjunct *X*. We do not choose between the two representations but continue to view the conjoin operation as a part of our formalism.

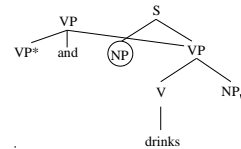


Figure 6: Coordination as adjunction.

For example, applying *conjoin* to the trees  $Conj(and)$ ,  $\alpha(eats)_{\{1\}}$  and  $\alpha(drinks)_{\{1\}}$  gives us the derivation tree and derived structure for the constituent in (2) shown in Fig. 7.

(2) ...eats cookies and drinks beer.

In Fig. 7 the nodes  $\alpha(eats)_{\{1\}}$  and  $\alpha(drinks)_{\{1\}}$  signify an operation left incomplete at address 1.

in (Joshi and Schabes, 1991). A coordinated node will never dominate multiple foot nodes. Such a case occurs, e.g., two auxiliary trees with substitution nodes at the same tree address are coordinated with only the substitution nodes in the contraction set.

<sup>8</sup>Merging in the graph-theoretic definition of contraction involves the identification of two previously distinct nodes. In the process of contraction over nodes in elementary trees it is the operation on that node (either substitution or adjunction) that is identified.

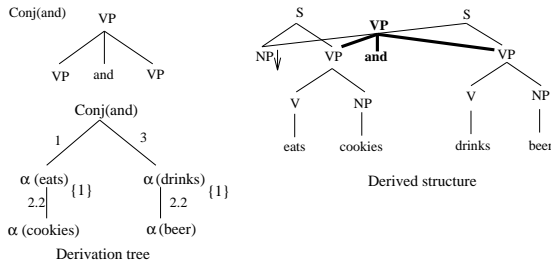


Figure 7: An example of the *conjoin* operation.

*The Effects of Contraction.* One of the effects of contraction is that the notion of a derivation tree for the LTAG formalism has to be extended to an acyclic *derivation graph*<sup>9</sup>. Simultaneous substitution or adjunction modifies a derivation tree into a graph as can be seen in Fig. 8.

If a contracted node in a tree (after the conjoin operation) is a substitution node, then the argument is recorded as a substitution into the two elementary trees as for example in the sentences (3) and (4).

- (3) Chapman eats cookies and drinks beer.
- (4) Keats steals and Chapman eats apples.

Fig. 8 contains the derivation and derived structures for (3) and Fig. 9 for (4). In Fig. 9 the derivation graph for sentence (4) accounts for the coordinations of the traditional nonconstituent “Keats steals” by carrying out the coordination at the root, i.e.  $S \text{ conj } S$ . No constituent corresponding to “Keats steals” is created in the process of coordination.

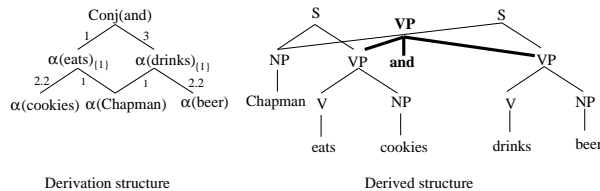


Figure 8: Derivation for *Chapman eats cookies and drinks beer*.

The derived structures in Figs. 8 and 9 are difficult to reconcile with traditional notions of phrase structure<sup>10</sup>. However, the derivation structure gives us all the information about dependency

<sup>9</sup>We shall use the general notation *derivation structure* to refer to both derivation trees and derivation graphs.

<sup>10</sup>McCawley (1982) raised the heterodox view that a discontinuous constituent structure should be given for right node raising cases, having the same notion of constituency as our approach. However, no conditions on the construction of such a structure was given. In fact, his mechanism also covered cases of parenthetical placement, scrambling, relative clause extraposition

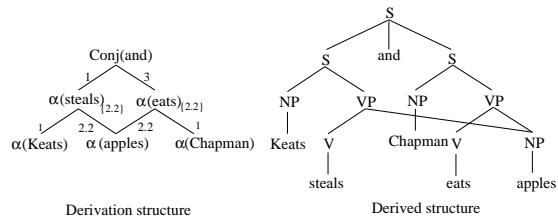


Figure 9: Derivation for *Keats steals and Chapman eats apples*.

that we need about the constituents. The derivation encodes exactly how particular elementary trees are put together. Obtaining a tree structure from a derived structure built by the conjoin operation is discussed in (Sarkar and Joshi, 1996).

Considerations of the locality of movement phenomena and its representation in the LTAG formalism (Kroch and Joshi, 1986) can also now explain constraints on coordinate structure, such as across-the-board exceptions to the well known coordinate structure constraint, see Fig. 10. Also in cases of unbounded right node raising such as *Keats likes and Chapman thinks Mary likes beans*, *Chapman thinks* simply adjoins into the right conjunct of the coordinate structure<sup>11</sup>.

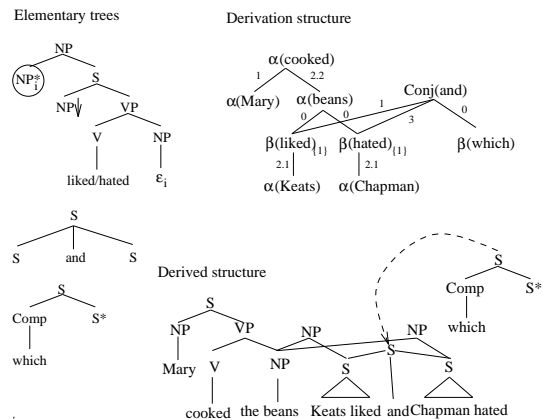


Figure 10: Derivation for *Mary cooked the beans which Keats liked and Chapman hated*.

## 5 Contractions on Anchors

An LTAG along with the operations of substitution and adjunction also has the implicit operation of lexical insertion (represented as the diamond mark in Fig. 11). Under this view, the

and heavy NP shift.

<sup>11</sup>A comparison of this paper’s approach with the derivational machinery in CCG and the devices of 3-D coordination is done in (Sarkar and Joshi, 1996).

LTAG trees are taken to be templates. For example, the tree in Fig. 11 is now represented as  $\langle \alpha(\text{eats}), \{1, 2.1, 2.2\} \rangle$ .

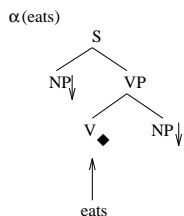


Figure 11: Lexicalization in a LTAG.

If we extend the notion of contraction in the conjoin operation together with the operation of lexical insertion we have the following observations: The two trees to be used by the conjoin operation are no longer strictly lexicalized as the label associated with the diamond mark is a preterminal. Previous uses of conjoin applied to two distinct trees. If the lexicalization operation is to apply simultaneously, the same anchor projects two elementary trees from the lexicon. The process of contraction ensures that the anchor is placed into a pair of LTAG tree templates with a single lexical insertion.

*Gapping.* Using this extension to *conjoin*, we can handle sentences that have the “gapping” construction like sentence (5).

- (5) John ate bananas and Bill strawberries.

The conjoin operation applies to copies of the same elementary tree when the lexical anchor is in the contraction set. For example, let  $\alpha(\text{eats})$  be the tree selected by *eats*. The coordination of  $\alpha(\text{eats})_{\{2.1\}}$  with a copy of itself and the subsequent derivation tree is depicted in Fig. 12<sup>12</sup>.

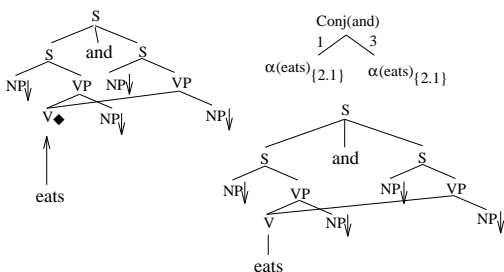


Figure 12: Handling the gapping construction using contractions.

An extension of the approach here will be to permit the conjoin operation to create contractions on *all* the nodes in contraction sets that it

<sup>12</sup>In English, following Ross (1970), the anchor goes to the left conjunct.

dominates during a derivation, allowing us to recognize cases of gapping such as: *John wants Penn to win and Bill, Princeton.* and *John wants to try to see Mary and Bill, Susan.*

*Coordinating Ditransitive verbs.* In sentence (6) if we take the position that the string *Mary a book* is not a constituent (i.e. *give* has a structure as in Fig. 13), then we can use the notion of contraction over the anchor of a tree to derive the sentence in (6). The structure we derive is shown in Fig. 14.

- (6) John gave Mary a book and Susan a flower.

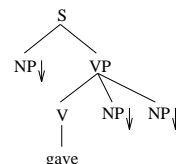


Figure 13: Tree for a ditransitive verb in LTAG.

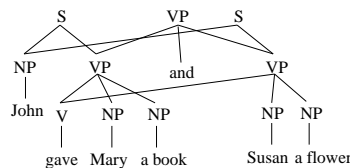


Figure 14: Derived tree for *John gave Mary a book and Susan a flower*.

*Interactions.* Permitting contractions on multiple substitution and adjunction sites along with contractions on the anchor allow the derivation of *sluicing* structures such as (7) (where the conjunct *Bill too* can be interpreted as *[John loves] Bill too* or as *Bill [loves Mary] too*<sup>13</sup>).

- (7) John loves Mary and Bill too.

## 6 Parsing Issues

This section discusses parsing issues that arise in the modified TAG formalism that we have presented. We do not discuss general issues in parsing TAGs, rather we give the appropriate modifications that are needed to the existing Earley-type parsing algorithm for TAGs due to Schabes and Joshi (1988).

The algorithm relies on a tree traversal that scans the input string from left to right while recognizing the application of the conjoin operation. The nodes in the elementary trees are visited in a top-down left to right manner (Fig. 15). Each dot in Fig. 15 divides the tree into a left context and a

<sup>13</sup>Whether this should be derived syntactically is controversial, for example, see (Steedman, 1990).

right context, enabling the algorithm to scan the elementary tree while trying to recognize possible applications of the conjoin operation.

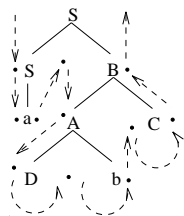


Figure 15: Example of a tree traversal

The derived structure corresponding to a coordination is a composite structure built by applying the conjoin operation to two elementary trees and an instantiation of the coordination schema. The algorithm never builds derived structures. It builds the derivation by visiting the appropriate nodes during its tree traversal in the following order (see Fig. 16).

1 2 ... 3 4 ... 5 6 ... 2' 7' ... 3' 4' ... 5' 6' ... 7 8

The algorithm must also compute the correct span of the string for the nodes that have been identified via a contraction. Fig. 16 gives the possible scenarios for the position of nodes that have been linked by a contraction. When foot nodes undergo contraction, the algorithm has to ensure that both the foot nodes share the subtree pushed under them, e.g. 9 ... 10 and 9' ... 10' in Fig. 16(a). Similarly, when substitution nodes undergo contraction, the algorithm has to ensure that the tree recognized due by predicting a substitution is shared by the nodes, e.g. 11 ... 12 and 11' ... 12' in Figs. 16(b) and 16(c). The traversals 9 ... 10 should span the same length of the input as 9' ... 10', similarly for 11 ... 12 and 11' ... 12'. Various positions for such traversals is shown in Fig. 16. A derivation is valid if the input string is accepted and each node in a contraction spans a valid substring in the input. The complete and formal description of the parsing algorithm is given in (Sarkar and Joshi, 1996).

## 7 Conclusion

We have shown that an account for coordination can be given in a LTAG while maintaining the notion of a derivation structure which is central to the LTAG approach. We showed that fixed constituency can be maintained at the level of the elementary tree while accounting for cases of non-constituent coordination and gapping. We discussed the construction of a practical parser for LTAG that can handle these cases of coordination.

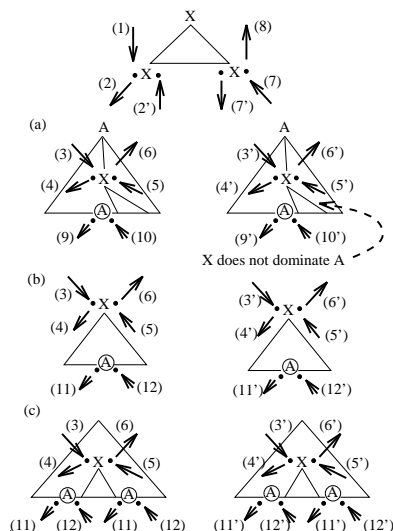


Figure 16: Moving the dot while recognizing a conjoin operation

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