On Some Similarities Between D-Tree Grammars and Type-Logical Grammars

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1 Introduction

This paper discusses some similarities between D-Tree Grammars and type-logical grammars that are suggested in the context of a parsing approach for the latter that involves compiling higher-order formulae to first-order formulae. This comparison suggests an approach to providing a functional semantics for D-Tree derivations, which is outlined.

2 D-Tree Grammars

The D-Tree Grammar (DTG) formalism is introduced in (Rainbow et al., 1995). The basic derivational unit of this formalism is the d-tree, which (loosely) consists of a collection of tree fragments with domination links between nodes in different fragments (that link them into a single graph).

(1)

The above example d-tree, drawn from (Rainbow et al., 1995), allows topicalisation of the verb’s object, as in (e.g.) Hotdogs, he claims Mary seems to adore t1, where NP1 is the fronted object, and NP2 the verb’s subject. The main operation for composing d-trees is subvention, which, loosely, combines two d-trees to produce another, by substituting a fragment of one at a suitable node in the other, with other (dominating) fragments of the first being intercalated into domination links of the second. The approach is motivated by problems of related formalisms (such as TAG and MCTAG-DL) involving linguistic coverage and the semantic interpretation of derivations.

3 Type-logical Grammar

The associative Lambek calculus (Lambek, 1958) is the most familiar representative of the ‘type-logical’ tradition within categorial grammar, but a range of such systems have been proposed, which differ in their resource sensitivity (and hence, implicitly, their underlying notion of ’linguistic structure’). Some of these proposals are formulated using a ‘labelled deduction’ methodology (Gabbay, 1996), whereby the types in a proof are associated with labels, under a specified discipline, which record proof information used in ensuring correct inferencing. Such a labelling system must be overlaid upon a ‘backbone logic’, commonly the implicational or multiplicative fragment of linear logic. For this paper, we can ignore labellings, and instead focus on the ‘core functional structure’ projected by linear formulae.

4 Implicational Linear Logic & First-order Compilation

In linear logic proofs, each assumption is used precisely once. Natural deduction rules of elimination and introduction for linear implication (→) are:

(2) \[
\begin{align*}
A &\vdash B : a & A : b &\vdash E \\
B : a &\vdash E & A : a &\rightarrow I \\
A &\vdash B : \lambda v. a
\end{align*}
\]

The proof in (3) illustrates ‘hypothetical reasoning’, where an additional assumption, or ‘hypothetical’, is used that is latter discharged. The involvement of hypotheticals is driven by the presence of higher-order formulae (i.e. functors seeking an argument that bears a functional type): each corresponds to a subformula of a higher-order formula.

1 See (Joshi et al., 1997; Henderson, 1992) for other work connecting categorial formalisms (Lambek calculus and CCG, respectively) to tree-oriented formalisms.
2 The indexation is my own, for expositional purposes.
3 A second operation, sister-adjunction, used in handling modification, is discussed later in the paper.
4 Multi-Component TAG with Domination Links (Becker et al., 1991).
5 The multiplicative fragment extends the implicative one with tensor (‘tensor’), akin to the Lambda product.
6 This means, most notably, that the representations discussed lack any encoding of linear order requirements, which would be handled within the labelling system.
7 Eliminations and introductions correspond to steps of functional application and abstraction, respectively, as the lambda-term labelling reveals. In the \(\rightarrow I\) rule, \([B]\) indicates a discharged or withdrawn assumption.
e.g. $Z$ in (3) is a subformula of $X \vdash (Y \vdash Z)$.

\[(3) \quad X \vdash (Y \vdash Z) : x \quad Y \vdash W : y \quad W \vdash Z : w \quad [Z : z] \quad W : (wz) \]

\[Y : (y(wz)) \quad \frac{X : x(\lambda z.y(wz)) \quad Y : (y(wz)) \quad W : (wz)}{X : x(\lambda z.y(wz))} \]

Hepple (1996) shows how deductions in implicational linear logic can be recast as deductions involving only first-order formulae (i.e. where any arguments sought by functors bear atomic types) and using only a single inference rule (a variant of $\ominus \Rightarrow$).

The rest of this paper explores the idea of providing a functional semantics for DTG derivations, or rather a higher-order functional semantics for DTG derivations. The approach envisaged is one in which each tree fragment (i.e. maximal unit containing no dominance links) of an initial derivation is associated with a lambda term. At the end of a derivation, the meaning of the resulting tree would be computed by working bottom up, applying

\[z \text{ falls within the scope of the abstraction, and so becomes bound.} \]

\[\frac{\phi : A \vdash (B : \alpha) : \lambda \alpha.u \quad \psi : B : \delta}{\pi : A[t/\delta]} \quad \alpha \subseteq \psi \]

5 Relating The Two Systems

The above compilation produces results that bear more immediate similarities to the D-Tree approach than the original type-logical system. First-order formulae are easily viewed as tree fragments (in a way that higher-order formulae are not), e.g. a word $w$ with formula $X \vdash n$-$pp$ might be viewed as akin to (5a) below (modulo the order of daughters which is not encoded). For a higher-order formula, the inclusion requirement between its first-order derivations is analogous to a domination link within a d-tree, e.g. a relative pronoun $rel/(s/np)$ would yield $rel \vdash s$ plus $np$, which we can view as akin to (5b).

By default, it is natural to associate the string of the initial formula with its main residue under compilation, as in (5b). Following proposals in (Moortgat, 1988; 1996), some categorial systems have used connectives $\dagger$ ('extraction') and $\ddagger$ ('fixation'), where $Y[Z]$ is a "$Z$ missing $Y$ somewhere" and a type $X[(Y[Z)]$ infixes its string to the position of the missing $Z$. Thus, a word $w$ with type $X[Z]$ compiles to $X \vdash Y[Z]$ and $Z$, is akin to (6a). For example, the PP pied-piping relative pronoun type $rel/(s/np)/(np/np)$, from (Morrill, 1992), which infixes to an NP site within a PP, is akin to (6b).

6 A Functional Approach to Interpreting DTG Derivations

The rest of this paper explores the idea of providing a functional semantics for DTG derivations, or rather of some DTG-like formalism, in a manner akin to that of categorial grammar. The approach envisaged is one in which each tree fragment (i.e. maximal unit containing no dominance links) of an initial derivation is associated with a lambda term. At the end of a derivation, the meaning of the resulting tree would be computed by working bottom up, applying
the meaning term of each basic tree fragment to the meanings computed for each complete subtree added in at the fragment’s frontier nodes, in some fixed fashion (e.g., such as in their right-to-left order). Strictly, terms would be combined using the special substitution operation of rule (4) (allowing variable capture in the manner discussed). Suitable terms to associate with tree fragments will be arrived at by exploiting the analogy between d-trees and higher-order formulae under compilation.

For example, consider a simple grammar consisting of the four d-trees in (7), of which only that for which has more than one fragment. Each tree fragment is associated with a meaning term, shown to the right of “:”. The two fragments in the d-tree for which each have their own term, which are precisely those that would be assigned for the two compiled formulae in (5b) (assuming the meaning term for the precompilation formula rel/(s/np) to be just which). This grammar allows the phrase-structure (8a) for Mary saw John, whose interpretation is produced by ‘applying’ the term for saw to that for the NP John (i.e., the subtree added in at the rightmost frontier node of saw’s single tree fragment), and then to that of the NP Mary, giving (saw j in). The grammar allows the tree (8b) for the relative clause which Mary saw. Here, the object position of saw is filled by the lower fragment of which’s d-tree, so that the subtree rooted at S has interpretation (saw z m). Combining this with the term of the upper fragment of which gives interpretation which(λz.saw m).

The tree composition steps required to derive the trees in (8) would be handled in DTG by the sub-variation operation. As noted earlier, DTG has a second composition operation sister-adjunction, used in handling modification, which adds in a modifier subtree as an additional daughter to an already existing local tree. A key motivation for this operation is so that DTG derivation trees distinguish argument vs. modifier dependencies, so as to provide an appropriate basis for interpretation. Categorial grammars typically make no such distinction in syntactic derivation, where all combinations are simply of functions and arguments. Rather, the distinction is implicit as a property of the lexical meanings of the functions that participate. Accordingly, we recommend elimination of the sister-adjunction operation, with all composition being handled instead by sub-variation. Thus, a VP modifying adverbial might have d-tree (9a), and give structures such as (9b). Such an analysis requires a different lexical d-tree for saw to that in (7), one where the VP node is ‘stretched’ as in (10b) to allow possible inclusion of modifiers. As a basis for arriving at suitable functional semantics for (10b), consider the following. A categorial approach might make saw a function (np\s)/up with semantics saw. This function could be type-raised to (np\s)((np\s)((np\s)/np))/ with semantics (λf.f saw). By substituting the two embedded occurrences of (np\s) with the atom vp we get (np\s)((vp\(vp\np))/np), which compiles to first-order formulae as in (10a), which are analogous to the desired d-tree (10b), so providing the meaning terms there assigned. Using (10b) to derive the structure (8a) involves identifying the two

\[\sigma_1 = \lambda x\lambda y.((\lambda f.f\text{saw})(\lambda p.x)y)\]

This is not to say that the distinction has no observable reflex: modifiers are in general recognisable as endocentric categorial functors (i.e. having the same argument and result type).

Such an analysis is more in line with the standard TAG treatment than that of DTG.
VP nodes. Such a derivation gives the interpretation \(((\lambda f.f\text{ saw})(\lambda p.p\text{ jum}))\) which simplifies to (saw j um). A derivation of (2b) gives interpretation \(((\lambda f.f\text{ saw})(\lambda p.\text{clearly}(p\text{ jum}))\) which simplifies to (clearly saw j um).

For a ditransitive verb, we might want a structure providing more than one locus for inclusion of modifiers, such as (11). The semantics provided for this d-tree is arrived at by a similar process of reasoning to that for the previous case, except that it involves type-raising the initial categorial type of the verb twice (hence the subterm \((\lambda g.g(\lambda f.f\text{ sent}))\) of the upper fragment’s term).

\[
(11) \qquad \lambda x.\lambda y.((\lambda g.g(\lambda f.f\text{ sent}))((\lambda p.p)x)y)
\]

The interpretation approach outlined appears quite promising so far. We next consider a case it does not handle, which reveals something of its limitations: quantification. Following a suggestion of (Moortgat, 1996), the connectives \(\downarrow\) (‘extraction’) and \(\uparrow\) (‘infixation’) have been used in a categorial treatment of quantification. The lexical quantified NP everyone, for example, might be assigned type \(S|S|NP\), so that it has scope at the level of some sentence node but its string will appear in some NP position. First-order compilation yields the results (12a). The corresponding d-tree (12b) is unusual from a phrase-structure point of view in that it’s upper fragment is a purely interpretive projection, but this d-tree would serve to produce appropriate interpretations. So far so good.

A simple quantifier every has type \(S|NP|n\), to combine firstly with a noun, with the combined string of every+noun then infixing to a NP position. First-order compilation, however, produces the result (13a), comparable to the d-tree (13b), which is clearly an inappropriate structure. What we hope for is a structure more like that in (13c), but although it is perfectly possible to specify an initial higher-order formula that produces first-order formulae comparable to this d-tree, the results do not provide a suitable basis for interpretation. More generally, the highly restrictive approach to semantic composition that is characteristic of the approach outlined is such that a fragment cannot have scope above its position in structure (although a d-tree having multiple fragments has access to multiple possible scopes). This means, for example, that no semantics for (13c) will be able to get hold of and manipulate the noun’s meaning as something separate from that of the sentence predicate (c.f. s|NP), rather the former must fall within the latter.

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See (Shieber & Schabes, 1990) for a treatment of quantification within the Synchronous TAG formalism, in which the semantics is treated as a second system of tree representations that are operated upon synchronously with syntactic trees. Their account cannot be adapted to the present approach because their operations upon syntactic and semantics representations, though synchronous, are not parallel in the way that is rigidly required in categorial semantics.