Derivational and Representational Views of Minimalist Transformational Grammar

Thomas Cornell

University of Tübingen, Seminar für Sprachwissenschaft, Kleine Wilhelmstrasse 113, D-72074 Tübingen, Germany
e-mail: `cornell@sfs.nphil.uni-tuebingen.de`

Abstract. In this paper we cast the long-standing debate in transformational grammar over movement derivations vs. well-formedness conditions on chains in a new light. We claim that the argument itself is misguided: a transformational grammar should have *both* a derivational and representational interpretation, connected by soundness and completeness results. Second, we argue that the proper form of the representational interpretation is as an axiomatization of T-markers rather than P-markers (e.g., LF structures). Little of significance in representationalist approaches is lost by this move, however. Antecedent goverment conditions on chains, for example, can still be easily stated in terms of the kinds of T-markers that we propose. Many well-known problems for representational approaches are avoided, however. In addition, from a derivational perspective, global constraints on derivations become simple structural well-formedness conditions on T-markers. We offer a rigorous formalization of a simple system of T-markers and show its equivalence to a simple minimalist derivation system.

1 Introduction

The recent swing in modern transformational generative grammar from the focus on essentially axiomatic definitions of well-formed structures back to more derivational methods (e.g., Chomsky 1995) has added fuel to an old debate over the proper place of derivational and representational methods in transformational grammar, that is, whether it is better to account for extraction constructions by building them up with a series of movement transformations or by appeal to well-formedness conditions on chains (see, e.g., Brody 1995). In this paper we investigate the possibility of “having one’s cake and eating it too,” that is, the possibility of dealing with modern-day transformational grammar in a framework which provides both derivational and representational interpretations and where furthermore these interpretations are provably equivalent. For our approach to derivations we will mainly rely on formalizations of “minimalist” derivations offered by Stabler (see, especially, Stabler 1997), and we will focus here on presenting an equivalent representational system.

Let us define a representation system for a transformational grammar as an axiomatic definition of a set of well-formed structures which we will call *T-*

markers. The term is adapted from Chomsky (1975/55), and is meant to be understood by analogy to P-markers (phrase structure trees), which are structures which record the history of a derivation from a phrase structure grammar, and serve simultaneously as a static, declarative analysis of the constituent structure of a sentence.

There are a number of reasons to want a declarative picture of "structure at the level of transformations" beyond the desire to clarify debates about Universal Grammar and how to describe it. Maybe most importantly, in a setting in which economy conditions on derivations play such a large role, it is crucial to have a good static picture of a derivation. Constraints that hold on entire derivations (e.g., that all features be checked, or that Spell Out occur as soon as all strong features have been checked) then become simple structural well-formedness conditions, for example. Beyond this, addressing more global "economy" conditions, we can expect to use techniques from model theory or denotational semantics to order and structure sets of T-markers in ways which support a clear mathematical understanding of which derivations should be taken to be "less than" which others. Simply put, if one wants to compare derivations, then being able to treat derivations as objects is going to be necessary.

Other motivations come from concerns of computational linguistics. Suppose that we want to actually compute syntactic structures, and we are given only a derivation system. This is already a procedural system but not necessarily a computationally efficient one, and we are somewhat limited as to the ways in which we can construct equivalent but more efficient procedural interpretations of grammar. Equivalent in what sense, we might ask, to start with. A representation system can help here, in that it offers a notion of equivalence among derivations (namely: two derivations are equivalent if they have the same representation) which is independent of the chosen order of processing steps.

Finally, we know already from logic and computer science that the more ways one has of looking at a problem the better, in particular if those ways are equivalent. A classic example comes from the formally very distinct approaches to the tricky notion of logical consequence offered by proof theory and model theory, which are (in almost all popular logics) equivalent in the sense made precise in theorems of soundness and completeness. Apart from its practical usefulness this equivalence gives us some confidence that we have actually got a handle on what Consequence is. Similarly, the many different equivalent characterizations of computation give us confidence in the Church-Turing hypothesis that we have at least got the idea of Computation surrounded, if not captured. The fact that we can entertain such formally different approaches to Universal Grammar as those employed in Government Binding theory and in the Minimalist Program already suggests that Grammar, even assuming that the transformational generative grammar tradition is basically correct about it, is another one of these slippery notions, which must be approached cautiously and from a number of angles.

The simplest and most uncontroversial notion of T-marker which fits the Minimalist Program is just a term in an algebra with operations Merge and

Move (or "Attract") with sets or sequences of features as its constants. Such a term is much like a P-marker in that it represents not a single unique derivation but rather an equivalence class of derivations, in that distinct subtrees can be constructed in any order, but the operations used and the arguments they are used upon are fixed. Unlike a P-marker, however, such T-markers have never seemed to offer much insight as static representations of the syntactic structure of a sentence.

The least obvious and most controversial notion of a T-marker comes from a tradition of proposing representational versions of transformational grammar with its roots in trace theory. The central proposal there, most obvious in recent work of Michael Brody (e.g., Brody 1995), but phrased here in our own terms, is that the final P-marker in a transformational derivation—i.e., LF—is also a T-marker. In this case the proposed representation is very revealing of syntactic structure, but it is not at all clear that it is adequate as the representation of the history of a transformational derivation. This proposal is controversial mainly as a result of the fact that the proposed representation system is not constructed so as to match any derivation system. There are really two claims rolled into one here: that LFs capture all the information necessary to reconstruct their derivation and that the set of well-formed LFs can be defined independently of any derivation system. The first point is the starting point that motivates representationalist syntax, but it is the second that is really the focus of empirical and formal research. Things are complicated by the fact that (a) claims about Universal Grammar may differ even when the assumed derivation and representation systems are equivalent and (b) neither side of the debate develops adequate versions of the other side's formal foundations. So claims tend to take the form: derivations are unnecessary because representations are empirically adequate, and counter claims take the form: representations are not empirically adequate. (The reader may freely substitute "derivation" for "representation" and vice versa in the preceding sentence.) One goal of the research reported on here is to try to tease apart substantive claims about Universal Grammar on which Brody and Chomsky, for instance, certainly disagree, from formal claims about the properties of derivations and representations.

Our own proposal is intermediate between these two poles. It takes considerable inspiration from Brody's work, in particular his focus on chains. On the other hand our representation system is developed with the specific intention of being equivalent to a derivation system. The fact that we even use the term "T-markers" is a symptom of this focus. The term is not used in derivational approaches, since something like a derivation term is only interesting as a summary of a derivation, and does not offer particular insights into the structure of sentences. Nor is it used in pure representational approaches, which, as noted, focus instead on an empirically adequate axiomatization of LF structures (or (DS,SS,PF,LF) quadruples, in older GB era proposals).

The organization of this paper is in three main parts. In the remainder of this introduction we present our ideas informally, motivated as a solution to some problems for the LF-as-T-marker proposals. There follows a section in which we develop these ideas rigorously. Finally, we consider the kinds of derivation systems that Stabler (1997) has proposed, and sketch the proof of a sort of soundness and completeness result for our representation system and a Stabler-style derivation system. We have attempted to make the presentation as self-contained as possible in such a limited space. However, as far as our motivations and design decisions go, we must here and there assume some familiarity with the Minimalist Program, as it is presented in Chomsky (1995), though for the most part some familiarity with Government-Binding theory will suffice. Also we will at various points lean rather heavily on Stabler (1997); indeed in many respects this paper is a response to the line of research reported there.

1.1 Two Puzzles for the geometry of chains.

In this section we present two famous problems for the geometry of chains which make it difficult to formulate the notion of "well-formed chain" at the level of LF and without reference to any derivation of that chain. In Fig. 1(a), a head a moves to incorporate into another head b which locally governs it, and then the complex $[a\ b]$ head moves to incorporate into yet another head c which locally governs it in turn.[1] Each movement step is extremely local. The whole procedure can clearly be iterated at will to allow the formation of arbitrarily complex word-level structures from a sequence of extremely simple movement operations. Even after two such movements, however, the chain link—depicted as a dotted line in the figure—which connects the head we moved first (here a) to its trace (written here t_a) is no longer local, at least not in the same simple sense as in the movement derivation. It becomes quite challenging to state general well-formedness conditions on chains that will allow structures such as those in Fig. 1(a), while ruling out all the unacceptable structures, such as that shown in Fig. 1(b). This structure is derived by moving a across b, which is generally barred. However, the relevant chain link is superficially rather similar to the acceptable case. In particular, a governs its trace and—since b later also moves to c—only a trace intervenes, just as in the good example.

At least the antecedent a in Fig. 1(a) still governs its trace. In Fig. 2 we present, schematically, a structure in which this keystone of the traditional theory of chains is violated. In this example, a phrase aP first moves out of bP to attach to a specifier position in cP. Subsequently, bP itself moves to some higher position, "abducting" the trace of aP. (We have represented the target of movement as a higher specifier or adjunct in cP to keep the tree small.) In the resulting structure aP no longer governs its trace.[2]

[1] We use a two valued X-bar notation here, distinguishing only word internal or "0 level" nodes from word external or "phrase level" nodes.

[2] Such a construction may arguably be exemplified by the case of Remnant Topicalization in German (Müller 1998 and refs.). For example:

$[_{\mathrm{VP}}$ Gelesen t_2 $]_1$ hat [das Buch]$_2$ keiner t_1.
read has the book$_{\mathrm{acc}}$ no-one$_{\mathrm{nom}}$

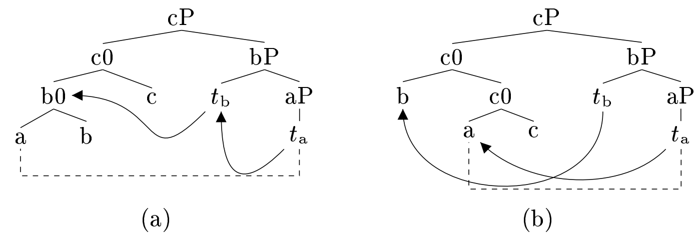

Fig. 1. (a) A complex but well-formed head-movement construction. (b) A similar but ill-formed head-movement construction.

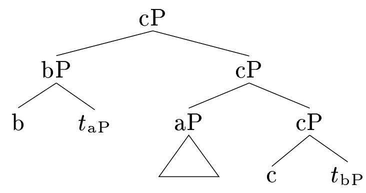

Fig. 2. An apparent violation of the antecedent government condition.

1.2 T-Markers: Informal Presentation

We first lay out our solutions to the foregoing puzzles informally. The intuitions involved are rather easy to grasp, though the execution is rather tricky in detail. Traditionally, two types of solutions have been offered for puzzles such as those in Sect. 1.1: Reconstruction and the Copy Theory of movement. Reconstruction allows for a moved expression to be "reconstructed" in the position of one of its traces, and is independently motivated by such constructions as backwards anaphora: *Pictures of himself always amuse John.* It can be used in our problem cases to reconstruct the derivation stages at which head chain links were local and an antecedent did indeed govern its trace. The copy theory of movement just proposes that "traces" are in fact copies of the moved expression, so, for example, the locality of head a to its trace can be determined by examining the copy of the complex head $[a\ b]$ that b leaves behind when it moves to c. Both of these solutions are based on the same essential idea: that the internal structure of a phrase is potentially accessible from any one of the chain of positions through which that phrase has been moved. Our proposal is to isolate this essential idea and use it as the basis of structures which capture in a single representation all (and only) the essential information about a transformational derivation. Adopting the terminology of Chomsky (1975/55), we refer to these structures as *T-markers.*

Consider first the case of "trace abduction" illustrated in Fig. 2. This example is more exotic and controversial than the head movement example, but the structures involved are simpler, as it involves no head movement or head adjunction structures. This tree contains three phrases, projected from the three heads a, b and c, and two chains $\langle a\mathrm{P}, t_{\mathrm{a}}\rangle$ and $\langle b\mathrm{P}, t_{\mathrm{b}}\rangle$. Let us think of the nodes in a tree as positions that expressions can occupy. Then we have two main types of position: phrasal positions, i.e., positions to which an expression can be attached, and chain positions, i.e., positions through which or to which an expression moves. From this perspective, all non-terminal nodes in the tree are phrasal positions, but some are also at the same time chain positions. In fact, if we adopt the standard assumption that all potentially movable expressions form chains, then we have also to include the trivial XP chain $\langle c\mathrm{P}\rangle$. In Fig. 3(a) we see the tree from Fig. 2, with the nodes relabeled to indicate their distinct functions as both phrasal and chain positions. Here chain positions are indicated with an asterisk, e.g., $a\mathrm{P}^*_0$ is the root position in the chain of aP, i.e., the trace of aP.

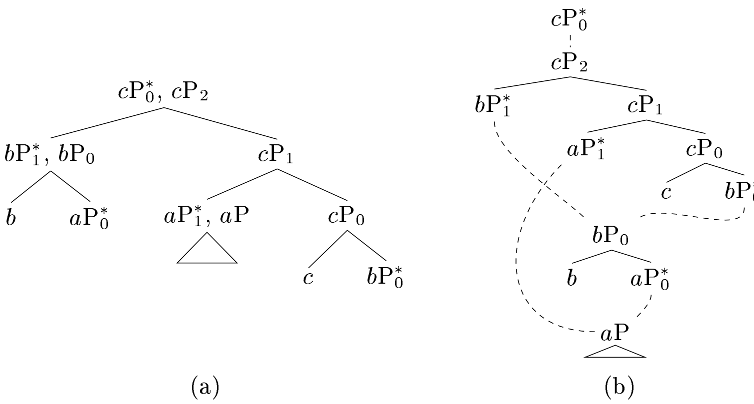

Fig. 3. Analyzing Fig. 2: (a) with phrase and chain positions; (b) an "exploded view" of (a).

Our rather simple proposal is just this. We propose to separate chains from phrases in a rather radical sense: chain positions and phrase positions will be treated as completely separate objects. Chain positions represent the *external* syntax of a construction, that is, the way it takes part in larger constructions, and phrase positions represent the *internal* syntax of a construction, that is, the way in which smaller constructions are combined to form it. Observe that this description of chains and phrases makes no reference to movement transformations; in particular, there is no sense in which chains are essentially conceptually just the vapor trails of moving phrases.

The structure displayed in Fig. 3(b) presents a sort of "exploded view" of the structure in Fig. 3(a), which splits the nodes which are both phrasal and chain positions into two separate nodes. We also add arcs back from each chain position to the maximal element of the corresponding phrase, indicating that the target phrase may potentially be spelled out in any one of its chain positions. In this way the single graph structure of Fig. 3(b) can be used to represent any stage of the corresponding transformational derivation, basically by choosing one of the chain-to-phrase arcs from each chain as the "spell-out position" for that stage. For example, the tree in Fig. 3(a) arises from choosing the highest-numbered element of each chain as its spell-out position.

Note that in Fig. 3(b), all chain positions of one head are attached to phrasal positions of some other head. All interaction between heads thus depends on these chain position-phrase position links. This composition of structures out of nodes of opposite polarities rather directly reflects the theory of feature checking in the minimalist program, according to which derivations are driven by the attraction between oppositely charged features.

This T-marker, ignoring for now the different kinds of arcs that are drawn here, is a rooted directed acyclic graph (RDAG), a structure with many properties in common with trees. In particular, it is still possible to define a dominance partial order, and therefore also the c-command relation, which is the keystone of the government relation. Let us ask, then, whether or not the chain position $a\mathrm{P}_1^*$ c-commands its trace, the chain position $a\mathrm{P}_0^*$. Since $a\mathrm{P}_1^*$ is immediately dominated by $c\mathrm{P}_1$, the question reduces to the question of whether $c\mathrm{P}_1$ is an ancestor of $a\mathrm{P}_0^*$. It is, as witnessed by the path:

$$c\mathrm{P}_1 \rightarrow c\mathrm{P}_0 \rightarrow b\mathrm{P}_0^* \dashrightarrow b\mathrm{P}_0 \rightarrow a\mathrm{P}_0^*$$

The "trace abduction" problem simply disappears. More precisely, the chain position $b\mathrm{P}_1^*$ at which $b\mathrm{P}$ is spelled out in Fig. 2 simply plays no role in the computation of the c-command relation between $a\mathrm{P}_1^*$ and $a\mathrm{P}_0^*$. Unlike a P-marker with indexed traces, the crucial structural properties of the T-marker in Fig. 3 are invariant under the movement transformation that "abducts" the trace of $a\mathrm{P}$ in Fig. 2. Put another way, since $a\mathrm{P}_1^*$ c-commands $a\mathrm{P}_0^*$, there must exist a corresponding derivation in which, at some stage, $a\mathrm{P}$ could have moved to position $a\mathrm{P}_1^*$ from position $a\mathrm{P}_0^*$.[3]

What we have done, by separating chain positions from phrasal positions, is to separate the problems of chain geometry (government and locality) from the problems of spell-out. Spell-out, in a very general sense which includes both surface and LF interpretation, can be defined very simply by selecting from every chain one position as its spell-out position. Then the spell-out function, applied to a spell-out position in a chain, is defined as having the same value as that function applied to the maximal phrasal position; at all other chain positions its value is nil.

In this way a single T-marker can stand for the entire sequence of (forests of) P-markers that define a derivation. A derivation necessarily involves much needless copying of unaffected structure from one stage to the next. The T-markers that we propose collect just what is essential from the derivation in a single

[3] This could be a problem, in fact. While Remnant Topicalization is attested and must be accounted for, most languages disallow trace-abduction structures. Note that disallowing such movements is a matter of placing a condition on the chain of b, not a: $b\mathrm{P}$, containing a trace, should be frozen in place.

structure. This in turn allows us to consider how to construct a Government-Binding style, purely declarative, axiomatic definition of transformational syntactic structures, that is, to pursue model theoretic syntax despite the resolutely proof theoretic character of most current theorizing within the minimalist program.

Consider now what we would do with the head movement examples. The "exploded view" of the tree in Fig. 1(a) is shown in Fig. 4. The solution to that puzzle will be seen to follow essentially the same lines as the trace abduction example, that is, we find that the crucial structural properties of our T-markers are invariant under movement transformations owing to the separation of structural conditions on chains from the theory of spell out. Note however that our structures become somewhat more complex here, owing to the presence of both XP and X0 chains.

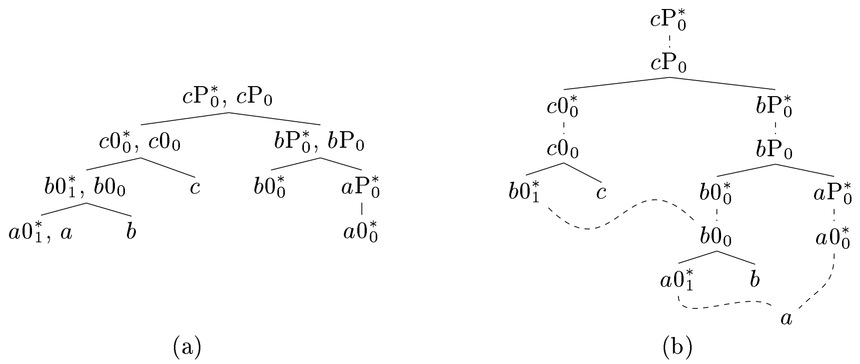

Fig. 4. Complex head movement: (a) phrase and chain positions; (b) exploded view.

Consider again the paths that witness the c-command relation between the two moved heads b and a and their traces. In the case of $b0_1^*$, the first category that completely dominates it is $c\mathrm{P}_0$, and in the case of $a0_1^*$ it is $b\mathrm{P}_0$.[4] Then the paths down to the traces $b0_0^*$ and $a0_0^*$ are as follows.

$$b0_1^* : \; c\mathrm{P}_0 \to b\mathrm{P}_0^* \dashrightarrow b\mathrm{P}_0 \to b0_0^*$$
$$a0_1^* : \; b\mathrm{P}_0 \to a\mathrm{P}_0^* \dashrightarrow a\mathrm{P}_0 \to a0_0^*$$

Again, the structural deformation of the chain link (a, t_a) (here $(a0_1^*, a0_0^*)$) plainly visible in Fig. 1(a) is simply absent here, because we have separated the problem of how the structure should be spelled out from the problem of

[4] The relevant notion of "dominance" here is in terms of "categories" rather than "segments of categories". See Chomsky (1986) for details. However, below we will observe that in the Minimalist Program a stronger condition than c-command holds, for which a proper understanding of the category/segment distinction is unnecessary.

the well-formedness of its chains. In a real structure the paths would not be quite so isomorphic of course, since one XP might have a different number of specifiers from the other, for example. Nonetheless, the same conditions that govern locality in a movement transformation hold here of the corresponding chain links, which is the crucial point. For reasons of space we do not illustrate the (ill-formed) T-marker for the (underivable) structure in Fig. 1(b). It is left as a simple exercise for the reader to verify that in this case the higher chain position of a will be found to c-command a chain position of b and that chain position of b to c-command the trace of a yielding the same violation of the Head Movement Condition as would the corresponding derivation.

2 The Formalism

2.1 Structures

The syntactic framework we are developing here is lexicalist in nature, that is, the material for building well-formed syntactic structures, or, equivalently, the constraints which isolate just the well-formed structures, all originate with lexical items. We will have more to say about the syntactic content of lexical items in Sect. 2.2. For the moment we simply observe that any given syntactic structure will be the extension in syntax of a particular multiset of lexical items, called in Chomsky (1995) the *numeration*. In what follows we will reserve the (often overloaded) term *head* for lexical item instances from the numeration.

The simplest definition of T-markers adopts the informal notation of Sect. 1.2 fairly directly. That is, we think of T-markers as structures over a set $\mathcal{U}$ of abstract positions, some of which are head positions. The rest of $\mathcal{U}$ is partitioned into phrases and chains, which are sequences of positions (which we will assume to be finite). We say of a phrase or chain position x such that $\mathsf{head}(x) = y$ that "x extends y." Phrases may be empty, but chains will always be considered to contain at least one element, mainly for ease of presentation.

Definition 1 (Extended Numeration). *An* extended numeration *is a structure* $\mathcal{A} = \langle A, \mathsf{head}, 0, \mathrm{P}, 0^*, \mathrm{P}^*, \leq \rangle$*, with unary operations* $\mathsf{head}, 0, \mathrm{P}, 0^*, \mathrm{P}^*$ *and binary relation* $\leq$*.* head *maps positions to their head positions (and is the identity on head positions).* $0, \mathrm{P}, 0^*, \mathrm{P}^*$ *(written postfix) map positions to subsets of* A*, called* phrases *and* chains*. For all phrases and chains* C*,* $\leq$ *restricted to* C *is required to be a total order. That is, phrases and chains are required to be sequences of positions. In addition they are required to be disjoint from each other.*

We will often use subscripts to indicate relative position in the $\leq$ order. The direction of the $\leq$ ordering reflects distance from the head position, so that, for instance, $x\mathrm{P}_0$ is the structurally lowest position in $x\mathrm{P}$ and $x\mathrm{P}^*_0$ is the derivationally initial position of $x\mathrm{P}$.

The following convention simply makes the notation a little easier to use.

Convention 1.

$$(\forall x, y)[y = \mathsf{head}(x) \Rightarrow (x\mathrm{P}^* = y\mathrm{P}^* \wedge x\mathrm{P} = y\mathrm{P} \wedge x0^* = y0^* \wedge x0 = y0)]$$

This condition makes it possible to refer to $x\mathrm{P}_i$, for instance, without restricting x to head positions. Note that $x \in x\mathrm{P}$ now implies that x is a position in a word external phrasal extension. Informally, we will write "x is an XP position" for $x \in x\mathrm{P}$, and analogously for the other extensions.

Unlabelled T-markers, that is, T-markers without any concern for the distribution of lexical features, are got from extended numerations by attaching chain positions of one head to phrase positions of a distinct head. We call the attachment relation T.

Definition 2 (Unlabelled T-Marker). *$\mathcal{T} = \langle \mathcal{A}, T \rangle$, with $\mathcal{A}$ an extended numeration, T a binary attachment relation on A, such that*

$$(\forall x, y : T(x, y))[(x \in x\mathrm{P}^* \wedge y \in y\mathrm{P}) \vee (x \in x0^* \wedge y \in y0)] \tag{1}$$
$$(\forall x, y : T(x, y))[\mathsf{head}(x) \neq \mathsf{head}(y)] \tag{2}$$
$$(\forall x, y, z)[T(y, x) \wedge T(z, x) \Rightarrow y = z] \tag{3}$$
$$(\forall x)\big[(x \in x\mathrm{P} \vee x \in x0) \Rightarrow (\exists y)[T(y, x)]\big] \tag{4}$$
$$(\forall x)\neg(\exists y)[T(x0^*_0, y)] \tag{5}$$

T attaches chain positions to phrase positions (1) of distinct heads (2). Every phrasal position has a unique dependent attached to it by T (3, 4). Movement of any structure smaller than the entire phrase must necessarily leave a trace within the phrase. Therefore, the minimal position of every X0 chain must be found at the base of its head's XP. Therefore it must not be attached anywhere else, so we must exclude it from the domain of T (5).

The following convention makes some definitions easier.

Convention 2. *For all head positions x, we assume that $x0^*_0$ always exists.*

Elements of an extended numeration, and the T-markers we get by attaching them together, form rather dense and complex graphs. The following definition is helpful in getting useful pictures of the essential structure of T-markers.

Definition 3 (Immediate Dominance). *We write $x \lhd y$ for "x immediately dominates y," and $x \lhd^* y$ and $x \lhd^+ y$ for the reflexive and irreflexive transitive closures of $\lhd$. Then $\lhd$ is the smallest relation such that, for all positions z:*

$$(\forall x \in z\mathrm{P}^*)(\forall y \in z\mathrm{P})[x \lhd^+ y] \wedge (\forall x \in z0^*)(\forall y \in z0)[x \lhd^+ y] \tag{6}$$
$$(\forall x, y \in z\mathrm{P})[x \leq y \Rightarrow y \lhd^* x] \wedge (\forall x, y \in z0)[x \leq y \Rightarrow y \lhd^* x] \tag{7}$$
$$(\forall x)(\forall y)[T(x, y) \Rightarrow y \lhd x] \tag{8}$$
$$(\forall x \in z\mathrm{P}^* \cup z\mathrm{P})[x \lhd^+ z0^*_0] \wedge (\forall x \in z0^* \cup z0)[x \lhd^+ \mathsf{head}(z)] \tag{9}$$

The $\lhd$ relation is built up from $\leq$ restricted to phrases plus the attachment relation T; the $\leq$ relation on chains is replaced by links connecting chain positions directly to their maximal phrasal position (if it exists) or to the minimal $\mathrm{X0}^*$ position otherwise. It is the $\lhd$ relation which is actually pictured in the figures in Secs. 1.1 & 1.2. The dotted lines connecting chain positions to (maximal) phrasal positions in those figures correspond to $\lhd$ links contributed by (6).

Condition 1 (RDAG Condition). *For all T-markers $\mathcal{T}$, the graph of the $\lhd$ relation on $\mathcal{T}$ is required to be a rooted directed acyclic graph (RDAG).*

Proposition 1.

1. *With respect to $\lhd$, phrasal positions are binary branching and endocentric: one of the two daughters has the same head as the mother while the other is attached via T.*
2. *For all heads x except the head of the root, $x\mathrm{P}^* \neq \emptyset$.*

We derive (2) by noting that by the RDAG Condition every head x must be connected into the $\lhd$ graph. Only via chain positions can it be connected outside its own extension. If $\mathrm{x0}^*$ is nonempty then $\mathrm{x0}^*_0$ exists, and the parent of $\mathrm{x0}^*_0$, by the definition of T and $\lhd$, cannot fall outside of the extension of x, so only via an XP chain position can $\mathrm{x0}^*_0$ be connected outside its own extension. So xP^* must be nonempty, so as to connect either x or $x0^*_0$ to the rest of the graph.

We lose a global notion of precedence in these structures, in the sense that the order of sisters does not give rise to a partial order over the whole structure. Precedence order in illustrations of T-markers is conventional and reflects the sisterhood relationships of the corresponding phrase structure trees.

We present now some definitions and conditions of a more linguistic nature. Intuitively, a head connects its specifiers and word internal adjuncts to its complement in a way analogous to the way in which operators take scope in logic. Note that in these definitions no attempt is made to include a theory of locality.

Definition 4 (Domain). *The* domain *of a head x is the set of positions y such that $T(y, w) \wedge head(w) = x$.*

Definition 5 (Scope). *Suppose we are given a head x and a position z such that $x\mathrm{P}_0 \lhd z$. The* scope *of x is the subgraph of $\lhd$ rooted at z. That is, it consists of the $\lhd$ relation restricted to the set of positions y such that $z \lhd^* y$.*

Definition 6 ((Trace) Binding). *A non-minimal chain position x* binds *its predecessor y just in case x is in the domain of a head z and y is in the scope of z. That is, there is a w such that $T(x, w)$ and $w\mathrm{P}_0 \lhd^+ y$.*

Condition 2 (Trace Binding Condition). *All non-minimal chain positions must bind their predecessors.*

Note that our definition of domain has left open the possibility that an element in complement position can bind a trace. This is ruled out by the RDAG Condition, however.

Proposition 2. *Only minimal* XP^* *positions can attach to minimal* XP *positions:* $(\forall x = x\mathrm{P}_0)(\forall y)[T(y, x) \Rightarrow y = y\mathrm{P}_0^*]$.

Proof. Suppose that we attach $y\mathrm{P}_{i>0}^*$ to $x\mathrm{P}_0$. $y\mathrm{P}_i^*$ must bind its trace. It follows that $x\mathrm{P}_0 \lhd^+ y\mathrm{P}_{i-1}^*$ and so $y\mathrm{P}_i^* \lhd^* y\mathrm{P}_{i-1}^*$ and so $y\mathrm{P}_{max} \lhd^* y\mathrm{P}_{i-1}^*$. But we have by the definition of $\lhd$ (Def'n 3) that $y\mathrm{P}_{i-1}^* \lhd^+ y\mathrm{P}_{max}$. This introduces a loop into the graph of $\lhd$, violating the RDAG Condition (Cond. 1). $\square$

Proposition 3. *The trace binding relation is transitive and irreflexive and a total order for any particular chain.*

In light of this we could redefine our T-markers with $\lhd$ and trace binding as primitives and derive the $\leq$ ordering instead. The $\leq$ ordering is convenient to our purposes here because it very closely reflects the order of derivation.

2.2 Features

The ideas about syntactic structures presented in Sect. 2.1 are actually substantially independent of the main proposals of the minimalist program. They are in many ways suitable for use in more classical Government Binding (GB) theory, in fact. The Minimalist Program is concerned mainly with issues of *economy*; the most basic level at which these issues play a role is in the adherence of the Minimalist Program to an essentially *resource conscious* approach to derivation and representation, with features as the resources in question. Adding a step to a derivation is only possible if the lexical features exist to license it, and executing that step consumes some of those features, so that they cannot be used again by that derivation. Our approach to features here follows very closely the formalism of Stabler (1997).

Definition 7. *We assume a basic set of* feature labels*, partitioned into* attraction *features (Chomsky's "formal features") and* selection *features. All feature labels can appear in one of two polarities. We refer to negatively charged selection feature labels as* category *features, written* `x`*, positively charged selection feature labels as* selector *features, written* `=x`*, negatively charged attraction feature labels as* licensee *features, written* `-x`*, and positively charged attraction feature labels as* licensor *features, written* `+x`*. Among attractor features we distinguish* strong *and* weak *occurrences; this distinction plays a role in defining the surface order of constituents. We write* `+X` *for the strong version of a licensor feature. We assume here that all selectors are strong.*

For example, an interrogative determiner like English *which*, as in *which children*, selects a nominal argument and requires Case and Wh licensing. Such a lexical item could be given the features `d`, `=n`, `-case`, `-wh`. A relative clause complementizer might be given the features `c`, `=i`, `+wh`. In the Minimalist Program, movement of a determiner phrase like *which children* into the domain of the complementizer is driven by the need to check the `-wh` licensee against the `+wh` licensor. A strong `+Wh` licensor will cause overt movement; a weak `+wh` licensor will allow covert, "inaudible" movement.

As far as the syntax is concerned:

Definition 8. *A* lexical item *is a sequence of features.*

Definition 9 (Labelled T-Marker). *In a* labelled *T-marker, we associate each head position with a lexical item (instance), and we associate with the T-marker a map ϕ from features in the lexical item of a head x to positions extending x such that the following hold.*

1. *ϕ maps negative features to chain positions and positive features to phrasal positions.*
2. *ϕ maps all and only licensee features to nonminimal chain positions.*
3. *ϕ respects the sequential ordering of features in a lexical item. That is, Given two extensions x and y of a head z, and two features $\mathtt{f}_1$ and $\mathtt{f}_2$ mapped to x and y respectively and such that $\mathtt{f}_1$ precedes $\mathtt{f}_2$ in the lexical item, $\neg y \leq x$.*

Condition (2) reflects the division in the theory according to which Selection is a theory about minimal chain positions (e.g., the "Generalized Projection Principle" of Brody 1995) while Attraction is about movement, i.e., nonminimal chain positions. Condition (1) is motivated by the observation that, for example, a `-wh` determiner phrase will move to attach in the domain of a `+wh` complementizer, not vice versa.

Definition 10 (Feature Checking). *A pair of features of similar type (Attraction or Selection) and clashing polarity* check *each other if they are assigned to positions x and y such that $T(x, y)$. A position x in which a feature `f` could possibly be checked is called a* checking position *for `f`.*

Condition 3 (Representational Economy).

1. *All features associated with all head positions must be checked, except for the category feature of the root.*
2. *All arcs in T must check at least one pair of features.*

Condition (1) corresponds to (part of) the definition of a convergent derivation and condition (2) implements Chomsky's principle of Last Resort. Observe how these two conditions on derivations appear here as structural well-formedness conditions.

Proposition 4.

1. *Category features can only be checked in positions $x\mathrm{P}_0^*$. It follows that, since for all x, $x\mathrm{P}^* \neq \emptyset$, every head has a (unique) category feature.*[5]
2. *Complement position is never a checking position for attraction features. Therefore it must be a checking position for selection features.*
3. *If a head has any positive features, one of them must be a selector feature.*
4. *Positions $x0_0^*$ and head positions are never checking positions for any feature.*
5. X0 *internal positions are never checking positions for selection features.*

[5] I owe this observation to the anonymous reviewer.

(1) follows the fact that minimal XP chain positions can only be licensed by negative selection features, i.e., categories, and selection features can only be mapped to minimal chain positions. (2) is really a corollary of Prop. 2, given the definition of ϕ. (3) then follows from the Trace Binding Condition: without a selector feature no head would be able to attach to a scope, so it could not cancel any attractor features. (4) follows from the definition of feature checking and the definition of T. (5) is a direct corollary of (4) and the definition of ϕ: X0 internal positions are only checking positions for features which can be associated with nonminimal chain positions.

2.3 Spell-Out

Transformational generative grammar falls in the classical Saussurean tradition, taking the objects of interest to the theory of grammar to be sound-meaning pairs of some sort. In principle, in the Minimalist Program, the members of such pairs are instructions which can be interpreted by the articulatory-perceptual system, on the one hand, and the conceptual-intentional system on the other. In practice, it is usually taken to be sufficient to define a pair of P-markers which occur at some designated point in the derivation and which take the place of whatever programs the syntax should deliver from its lexical ingredients. We will here refer to these P-markers as PF and LF, though Chomsky himself may intend to reserve "PF" for the output of the phonological component and not as a strictly syntactic object. A little more formally, we take our T-markers to be such that we can define a pair of projection functions which will act to compute PF and LF P-markers from the overall T-marker.

Definition 11. *A* prominence function *is a choice function on chains, i.e., a function that maps a chain to a member of that chain.*

We will actually identify the levels of PF and LF with particular prominence functions, which select which chain position will be "spelled out" at the relevant interface level.

Definition 12. *We assume now that our basic feature labels include some which are* interpretable. *These are not polarized and play no (direct) role in feature checking. For any prominence function F we assume that some of these interpretable features are interpretable at the level of representation associated with F (e.g., PF or LF). We call these features F-*interpretable. *Given a head x, we write the F-interpretable features of x as $[x]_F$.*

Definition 13 (P-Markers). *P-markers are terms in an algebra of headed concatenation where we also distinguish between words and phrases, i.e., between* X0*'s and* XP*'s. We will use $>$ to indicate right-headed concatenation (specifier attachment) and $<$ to indicate left-headed concatenation (complement attachment) at the* XP *level, and $\blacktriangleright$ to indicate the corresponding concatenations at the* X0 *level (head adjunction). 0-ary elements (constants) are sequences of features or else the symbol λ.*

Definition 14 (Spell-Out Functions). *Given a prominence function F, we define the action of the spell-out projection function π_F from T-markers to P-markers as follows.*

1. On chains*: Given a chain position x in chain C, such that x immediately dominates (phrasal position) y,*

$$\pi_F(x) = \begin{cases} \pi_F(y) \ , \text{ if } x = F(C); \\ \lambda \ , \text{ otherwise.} \end{cases}$$

2. On phrases*: Recall that all phrasal positions are binary branching and endocentric, that is, exactly one daughter shares the same head. So, for phrasal node x such that $x \lhd y \wedge x \lhd z \wedge \mathsf{head}(x) = \mathsf{head}(y)$, we have the following.*

$$\pi_F(x) = \begin{cases} \begin{array}{c} < \\ \pi_F(y) \qquad \pi_F(z) \end{array} & \text{, if } x \text{ is } x\mathrm{P}_0 \ , \\ \begin{array}{c} > \\ \pi_F(z) \qquad \pi_F(y) \end{array} & \text{, if } x \text{ is } x\mathrm{P}_{i>0} \ , \\ \begin{array}{c} \blacktriangleright \\ \pi_F(z) \qquad \pi_F(y) \end{array} & \text{, if } x \text{ is in } x0 \ . \end{cases}$$

3. On heads*: $\pi_F(x) = [x]_F$.*

Proposition 5. *The possible prominence functions over a given T-marker form a partial order, defined pointwise based on the linear order of chain elements: $F \sqsubseteq F'$ iff for all chains $C \in \mathrm{X0}^* \cup \mathrm{XP}^*$, $F(C) \leq F'(C)$ in the $\leq$ order on positions. (In fact the prominence functions form a lattice.) We can extend this ordering even further, to the trees generated by the projection functions π_F and $\pi_{F'}$.*

Given this fact, we can state the *Strong Feature Condition*, which relates strong features to the surface order of constituents, as a definition of the PF prominence function.

Definition 15. *A chain position x is* strongly attached *to phrasal position y if a strong feature is checked by $T(x, y)$, or if x is minimal in its chain.A prominence function is* strong *if it selects only strongly attached positions.*

Condition 4 (Strong Feature Condition). *PF is the greatest strong prominence function.*

Note that this gets around so called Procrastinate Violations, constructions in which an expression must move to a weakly attached position before it can move to a strongly attached position. An account of such constructions has been rather awkward to state in derivational terms, since movement is supposed to carry along PF-interpretable material only if it is to check a strong feature.

We have no equivalent defining condition on LF. In general, we want LF to select the maximal position of every XP chain and the minimal position of every X0 chain, but reconstruction effects are often exceptions to this generalization. Lacking the space to present a comprehensive theory of reconstruction, we will sweep the problem under the rug.

3 On the Relation of T-Markers to Derivations

In the main we follow Stabler (1997) in our characterization of minimalist derivations. We depart from that treatment in one significant respect, namely that Stabler treats "head movement" as part of the theory of the Merge transformation rather than the Move transformation, making it a consequence of Selection rather than Attraction. Less significantly, the results of head movement are interpreted directly via concatenation of interpretable features, so no X0 internal structure is ever built in the syntax. Here we have taken pains to indicate X0 internal structure, introducing an explicit ▶ operator for the purpose.

Definition 16. *The* head *of a P-marker is the terminal found by recursively selecting the head subterm of a concatenation. We write* $t^{\max}$ *for the largest subexpression of a P-marker whose head is the same as the head of* t *and* $t^{0\,\max}$ *for the largest* ▶*-subexpression with the same head as* t*. We refer to the sister of* $t^{0\,\max}$ *as the* attraction domain *of the head of* t*.*

We will make use of the following rather informal notation. Given a P-marker t and a feature f, we write $t[f]$ for the result of adding f as the initial feature in the head of t.

Definition 17 (Merge).

$$\text{Merge}(t[\texttt{=f}], s[\texttt{f}]) = \begin{cases} \overset{<}{t \qquad s}\ , & \textit{if } t \textit{ is } t^{0\,\max}, \\ \overset{>}{s \qquad t}\ , & \textit{otherwise.} \end{cases}$$

For discussing movement we assume that we have as terminal elements not only lexical items but also variables $v_0, v_1, \ldots$. Then given P-markers $t, u_0, \ldots, u_k$, the expression $t(u_0, \ldots, u_k)$ will be taken to mean the substitution in t of u_i for v_i. We assume further that each v_i occurs at most once in t.

Definition 18 (Move). *Given a P-marker* t *containing two variables* v_0 *and* v_1*, such that* v_0 *is* $t^{0\,\max}$ *and* v_1 *occurs somewhere in the attraction domain of the head of* t*.*

$$\text{Move}(t[\texttt{+f}](t_1, t_2[\texttt{-f}])) = \begin{cases} \overset{>}{t_2 \qquad t(t_1, \lambda)}\ , & \textit{if } t_2 \textit{ is } t_2^{\max}, \\ t(\overset{\blacktriangleright}{t_2 \qquad t_1}, \lambda)\ , & \textit{if } t_2 \textit{ is } t_2^{0\,\max}, \end{cases}$$

We assume without further comment that the choice between whether to execute XP movement or head movement is determined by `+f`.

Definition 19. *A* derivation state *is a multiset of P-markers. A* derivation *is a sequence of derivation states such that each successive state S_{i+1} is the result of applying either* Merge *or* Move *to P-markers in S_i and replacing them with the result of the operation. A* numeration *is a derivation state containing only trivial P-markers. A derivation* converges *if its final state contains only a single P-marker, containing only a single category feature in its head. All other terminals must be λ.*

Definition 20. *We say that a T-marker $\mathcal{A}$* corresponds *to a derivation Δ just in case there is a bijection between edges in $T^{\mathcal{A}}$ and transformations in Δ such that:*

1. *Merge(t, u) corresponds to $T(u\mathrm{P}_0^*, t\mathrm{P}_j)$ for some j;*
2. *Moving an XP u in t corresponds to $T(u\mathrm{P}_{i>0}^*, t\mathrm{P}_{j>0})$;*
3. *Moving an X^0 u in t corresponds to $T(u0_{i>0}^*, t0_j)$.*

Observe that every edge in T will be of exactly one of these three forms.

Definition 21. *An ordering on T is* admissible *iff it meets the following conditions.*

1. *It obeys the internal ordering of phrase and chain positions: for all positions x and y, if $x \leq y$ then x appears no later than y in the ordering.*
2. *Given a head x, all phrase positions of x appear before all chain positions of x in the ordering.*
3. *Given a head x, $x\mathrm{P}_0$ appears before any position of $x0$ in the ordering and $x\mathrm{P}_0^*$ appears before any position of $x0^*$.*

Lemma 1. *For any T-marker $\mathcal{A}$, there exists an admissible ordering on its T relation.*

The derivation system we have presented includes no facilities for handling phonologically or semantically interpretable features, so we offer here only a relatively weak equivalence theorem. A stronger result, that the systems yield the same (PF,LF) pairs from the same numerations, is possible with only a little more work, however.

Theorem 1. *For every convergent derivation Δ there is a corresponding T-marker $\mathcal{A}$, and for every T-marker $\mathcal{A}$ there is a corresponding convergent derivation Δ.*

Proof. (Sketch) The first direction is easiest. Given an operation we just construct two new positions, assign them the correct heads and structural levels and add an appropriate edge to T, following Def'n 20. Since all operations extend the structure they affect, and since derivations are already linearly ordered, we can deduce the correct $\leq$ ordering on constructed positions from the order of operations in the derivation.

For the other direction, first assume an admissible ordering of T in $\mathcal{A}$ given to us by Lemma 1. The proof is an induction on T, so ordered. In the inductive step, we assume that we have processed a certain prefix of T, and constructed a corresponding derivation state. We now consider the next edge in T and construct a new derivation state. There are three kinds of edge to consider, as given by Def'n 20. The only bit of reasoning that does not come directly from the definition of admissible order involves Move operations. In these cases, we must assure that the attracting head actually has an attraction domain, and that the attraction domain includes the subtree we are instructed to move. That is, given an edge in T $(y\mathrm{P}^*_{i>0}, x\mathrm{P}_{j>0})$, we must be able to construct a Move operation moving $y\mathrm{P}$ from within the attraction domain of x.

By the well-formedness of $\mathcal{A}$, we know that $y\mathrm{P}^*_i$ antecedent governs $y\mathrm{P}^*_{i-1}$ in $\mathcal{A}$, that is, $x\mathrm{P}_0$ dominates $y\mathrm{P}^*_{i-1}$. By the inductive hypothesis and the definition of admissible order, we have already processed the T-edge connected to $x\mathrm{P}_0$; it connects some $z\mathrm{P}^*_0$ to $x\mathrm{P}_0$. Then by clause (2) of Def'n 21 we know that we must have processed all of the nodes of $z\mathrm{P}$ already, and all of the edges leading into them, and so also all of the phrases below those chain positions, and so forth. So we must have constructed already the entire attraction domain of x, including $y\mathrm{P}^*_{i-1}$, where $y\mathrm{P}$ is currently attached. So the application of Move is well-defined. The reasoning for head movement is the same, except that we must rely on clause (3) of Def'n 21 to assure that the attraction domain has already been constructed. □

Consider now an example, given in Fig. 5, on page 20. This is a T-marker for the sentence *Some linguist speaks every language*. Features of lexical items are given under every head position, and again in the positions to which they are mapped by ϕ. There is no head movement or head internal structure in this example, so we do not illustrate $x0^*_0$ positions. All positions, other than head positions and the minimal X0* positions that we have suppressed, are associated with some feature that is checked in that position. Order of features is respected; category features are always associated with minimal XP* positions; the licensee feature `-k` (for `-case`) is associated with the nonminimal XP* positions of the two DPs.

An admissible ordering of the T-edges is provided, with position in the order written next to the phrasal end of the edge. We also indicate which transformation that edge corresponds to (Mg for Merge, Mv for Move). This ordering corresponds to a convergent derivation for this sentence, in particular, the derivation presented in Sect. 2.1 of Stabler (1997).

Of the edges in T, only $(\mathrm{smP}^*_1, \mathrm{tP}_1)$ checks a strong feature, so PF will be the prominence function selecting the minimal position of every chain except for smP*, in which it selects smP^*_1. LF is the prominence function which selects the highest position of every chain. If $\pi_{pf}(c\mathrm{P}^*_0)$ and $\pi_{lf}(c\mathrm{P}^*_0)$ are superimposed, then together they yield the output of the derivation presented in Stabler (1997), except that the surviving category feature c is not output by either spell-out function but is retained by the derivation.

Such a structure could be computed from a numeration of lexical items by executing a convergent derivation and adding pieces to the T-marker at each derivation step, along the lines suggested in the proof of Th'm 1. Other ways readily suggest themselves, however. For example, we could first form the extended numeration by considering the features in each lexical item and constructing the positions to which they would have to be mapped. Within the formalism presented here, this is deterministic, and could even be done off line for an entire lexicon. We could then proceed to construct the T relation. Finally, we would have to check the $\lhd$ graph for loops, and verify that the antecedent government condition was satisfied. Observe that this algorithm is very similar to the construction of a Proof Net (cf. Lecomte 1997): unfold lexical type formulas (sequences of positive and negative types), attach them together with axiom links, which "check" them in the same way that T-edges check features here, and then check the resulting network for structural well-formedness. Here there are significant differences, since our chosen well-formedness conditions have a strictly linguistic rather than mathematical pedigree. The main point to observe, in any case, is the following: we can approach computational problems for transformational grammars from a much wider variety of perspectives than we might have imagined if we considered only the derivations themselves and not their underlying structure.

4 Conclusions

In this limited space we have only been able to present the foundations of an approach to transformational grammar which emphasizes the "soundness and completeness" of a derivation system with respect to a representation system. We have not dealt with successive cyclic movement, nor with issues of locality conditions on movements or chain links, nor have we dealt with economy conditions which force the consideration of multiple distinct derivations. Successive cyclic movement requires the ability to map a feature to multiple positions, but seems restricted to licensee features; the positive features then remain a fixed limit on the consumption of resources. As far as locality conditions go, one observes easily enough that they must be stated over single P-markers, since that is the domain over which the Move operation is defined, so they typically have a rather representational flavor to begin with. As far as economy conditions go, if one must compare derivations, then it seems essential to be able to treat derivations as objects. Some form of T-marker seems inevitable, then, in getting a decent mathematical grip on the economy of derivations. So none of these limitations seem insurmountable.

Finally, we have restricted ourselves here to addressing challenges to representational approaches. There are also a number of challenges to derivational approaches from the representationalist side (see, in particular, Brody 1995), and the adequacy of our two-sided system must be assessed from that direction

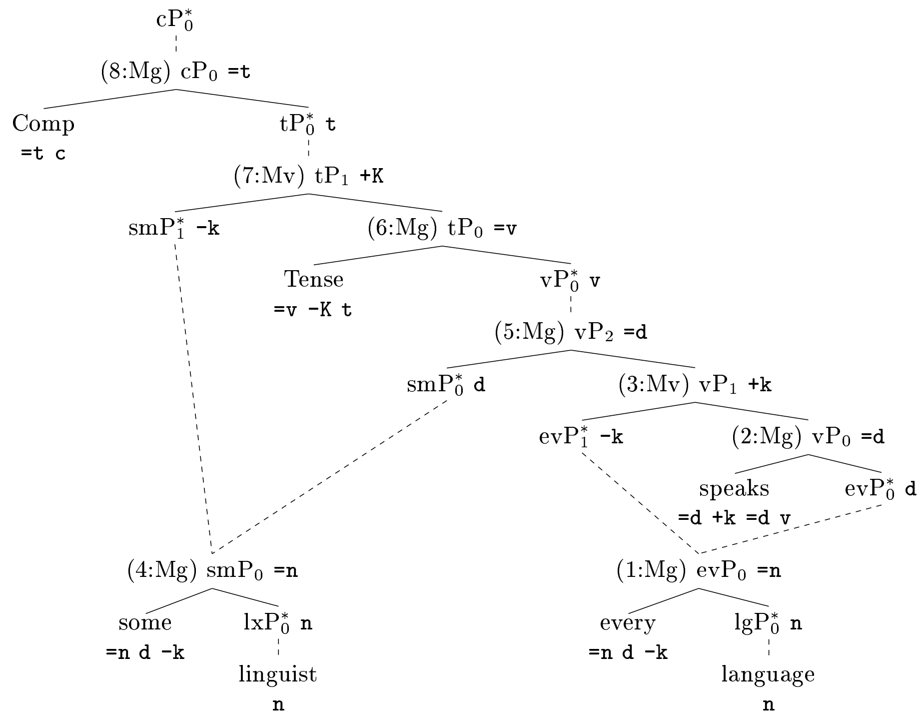

Fig. 5. T-marker for *Some linguist speaks every language.*

as well. These approaches typically offer an enriched notion of chain, which is what makes them challenging to derivational approaches, and so addressing the challenges they pose will require changes to the representation system as well.

References

Michael Brody. *Lexico-Logical Form: A Radically Minimalist Theory.* MIT Press, Cambridge, MA, 1995.

Noam Chomsky. *The Logical Structure of Linguistic Theory.* University of Chicago Press, Chicago, 1975/1955.

Noam Chomsky. *Barriers.* MIT Press, Cambridge, MA, 1986.

Noam Chomsky. *The Minimalist Program.* MIT Press, Cambridge, MA, 1995.

Alain Lecomte. POM-nets and minimalism. In Claudia Casadio, editor, *Proceedings of the IV Roma Workshop: Dynamic Perspectives in Logic and Linguistics.* SILPS Group in Logic and Natural Languages, 1997.

Gereon Müller. *Incomplete Category Fronting: A Derivational Approach to Remnant Movement in German.* Kluwer Academic Publishers, Dordrecht, 1998.

Edward Stabler. Derivational minimalism. In Christian Retoré, editor, *Logical Aspects of Computational Linguistics*, pages 68–95, Berlin, 1997. Springer. LNAI 1328.