The Combinatory Morphemic Lexicon

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Grammars that expect words from the lexicon may be at odds with the transparent projection of syntactic and semantic scope relations of smaller units. We propose a morphosyntactic framework based on Combinatory Categorial Grammar that provides flexible constituency, flexible category consistency, and lexical projection of morphosyntactic properties and attachment to grammar in order to establish a morphemic grammar-lexicon. These mechanisms provide enough expressive power in the lexicon to formulate semantically transparent specifications without the necessity to confine structure-forming to words and phrases. For instance, bound morphemes as lexical items can have phrasal scope or word scope, independent of their attachment characteristics but consistent with their semantics. The controls can be attuned in the lexicon to language particular properties. The result is a transparent interface of inflectional morphology, syntax and semantics. We present a computational system and show the application of the framework to English and Turkish.

1 Introduction

This study is concerned with the integrated representation and processing of inflectional morphology, syntax and semantics in a unified grammar architecture. An important issue in the integration is the mismatches in morphological, syntactic, and semantic bracketings. The problem was first noted in derivational morphology. Williams (1981) provided examples from English; semantic bracketings in (1a–2a) are in conflict with the morphological bracketings in (1b–2b).

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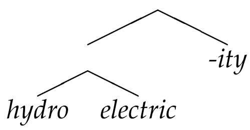

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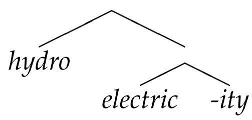

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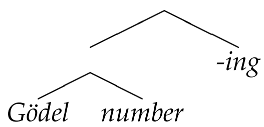

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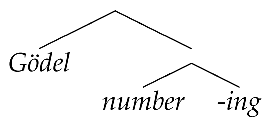

If the problem were confined to derivational morphology, we could avoid it by making derivational morphology part of the lexicon that does not interact with grammar. But this is not the case. Mismatches in morphosyntactic and semantic bracketing also abound. The paper addresses such problems and their resolution in a computational system.[1]

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1 Our use of the term **morphosyntax** needs some clarification. Some authors, e.g., Jackendoff (1997), take it to mean the syntax of words, in contrast to the syntax of phrases. By morphosyntax we mean those

Müller (1999, p.401) exemplifies the scope problem in German prefixes. (3a) is in conflict with the bracketing required for the semantics of the conjunct (3b).

(3) a. *Wenn [Ihr Lust] und [noch nichts anderes vor-]habt,*
if you pleasure and yet nothing else intend

können wir sie ja vom Flughafen abholen
can we them PARTICLE from.the airport pick up
'If you feel like it and have nothing else planned, we can pick them up at the airport.'

b. *Ihr Lust habt UND noch nichts anderes vorhabt*

Similar problems can be observed in Turkish inflectional suffixes. In the coordination of tensed clauses, the tense attaches to the verb of the rightmost conjunct (4a) but applies to all conjuncts (4b). Delayed affixation appears to apply to all nominal inflections (4c–e).

(4) a. *Zorunlu deprem sigortası [yürürlüğe girmiş] ama*
mandatory earthquake insurance effect enter-ASP but

[tam anlamıyla uygulanamamış]-tı
exactly apply-NEG-ASP-TENSE
'Mandatory earthquake insurance had gone into effect, but it had not been enforced properly.'

b. *yürürlüğe girmiş-ti ama tam anlamıyla uygulanamamış-tı*

c. *Adam-ın [araba ve ev]-i*
man-GEN car and house-POSS
'the man's house and car'

d. *Araba-yı [adam ve çocuk]-lar-a göster-di-m*
Car-ACC man and child-PLU-DAT show-TENSE-PERS1
'(I) showed the car to the men and the children.'

e. *Araba-yı sen-in [dost ve tanıdık]-lar-ın-a göster-di-m*
Car-ACC you-GEN friend and acq.-PLU-POSS-DAT showed
'(I) showed the car to the your friends and acquaintances.'

Phrasal scope of inflection can be seen in subordination and relativization as well. In (5a), the entire nominalized clause marked with the accusative case is the object of *want*. In (5b), the relative participle applies to the relative clause that lacks an object. The object's case is governed by the subordinate verb whose case requirements might differ from that of the matrix verb (5c). As we show later in this section, the coindexing mechanisms in word-based unification accounts of unbounded extraction face a conflict between the local and the nonlocal behavior of the relativized noun, mainly due to applying the relative participle *-diğ-i* to the verbal stem *ver* rather than the entire relative clause. A lexical entry for *-diğ-i* would resolve the conflict and capture the fact that it applies to nonsubjects uniformly.

aspects of morphology and syntax that collectively contribute to grammatical meaning composition. This is more in line with the inflectional-morphology-is-syntax view. In this respect, we will not address problems related to derivational morphology; its semantics is notoriously noncompositional and does not interact with grammatical meaning. Moreover, without a semantically powerful lexicon such as Pustejovsky's (1991), even the most productive fragment of derivational morphology is hard to deal with (Sehitoglu and Bozsahin, 1999).

(5) a. *Can* [*Ayşe'nin kitab-ı oku-ma-sı*]*-nı iste-di*
C.NOM A.-GEN book-ACC read-INF-AGR-ACC want-TENSE
'Can wanted Ayşe to read the book.'
lit. 'Can wanted Ayşe's-reading-the-book.'

b. *Ben* [*Mehmet'in çocuğ-a/*-u ver*]*-diğ-i kitab-ı oku-du-m*
I.NOM M-GEN child-DAT/*ACC give-REL.OP book-ACC read-TENSE-PERS1
'I read the book that Mehmet gave to the child.'

c. *Ben* [*Mehmet'in kitab-ı ver*]*-diğ-i çocuğ-u/*-a gör-dü-m*
I.NOM M-GEN book-ACC give-REL.OP child-ACC/*DAT see-TENSE-PERS1
'I saw the child to whom Mehmet gave the book.'

The morphological/phrasal scope conflict of affixes is not particular to morphologically rich languages. Semantic composition of affixes in morphologically simpler languages poses problems with word (narrow) scope of inflections. For instance, *fake trucks* needs the semantics (plu(fake truck)), which corresponds to the surface bracketing [*fake truck*]*-s*, because it denotes the nonempty nonsingleton sets of things that are not trucks but fake trucks (Carpenter, 1997). *Four trucks*, on the other hand, has the semantics (four(plu truck)), which corresponds to *four* [*truck*]*-s*, because it denotes the subset of nonempty nonsingleton sets of trucks with four members.

The status of inflectional morphology among theories of grammar is far from settled, but, starting with Chomsky (1970), there seems to be an agreement that derivational morphology is internal to the lexicon. LFG (Bresnan, 1995) and earlier GB proposals e.g. (Anderson, 1982) consider inflectional morphology to be part of syntax, but it has been delegated to the lexicon in HPSG (Pollard and Sag, 1994, p.35) and in the Minimalist Program (Chomsky, 1995, p.195). The representational status of the morpheme is even less clear. Parallel developments in computational studies of HPSG propose lexical rules to model inflectional morphology (Carpenter and Penn, 1994). Computational models of LFG (Tomita, 1988) and GB (Johnson, 1988; Fong, 1991) on the other hand, have been noncommittal regarding inflectional morphology. Finally, morphosyntactic aspects have always been a concern in Categorial Grammar (CG), e.g., (Bach, 1983; Carpenter, 1992; Dowty, 1979; Heylen, 1997; Hoeksema, 1985; Karttunen, 1989; Moortgart, 1988b; Whitelock, 1988), but the issues of constraining the morphosyntactic derivations and resolving the apparent mismatches have been relatively untouched in computational studies.

We briefly look at Phrase Structure Grammars (PSGs), HPSG, and Multimodal CG (MCG) to see how word-based alternatives for morphosyntax would deal with the issues raised so far. For convenience, we call a grammar that expects words from the lexicon a **lexemic** grammar, and a grammar that expects morphemes a **morphemic** grammar. A lexemic PSG provides a lexical interface for inflected words (X_0s) such that a regular grammar subcomponent handles lexical insertion at X_0.[2] In (4d), the right conjunct *çocuk-lar-a* is analyzed as $N_0 \to$ çocuk -PLU -DAT (or $N_0 \to N_{0'}$ -DAT, $N_{0'} \to N_{0''}$ -PLU, $N_{0''} \to$ Stem, as a regular grammar). Assuming a syncategorematic coordination schema, i.e. $X \to X$ *and* X, the N_0 in the left and right conjuncts of this example would not be of the same type. Revising the coordination schema such that only the root features coordinate would not be a solution either. In (4e), the relation of possession that is marked on the right conjunct must be carried over to the left conjunct as well. What is

2 But see Creider, Hankamer, and Wood (1995) who argued that the morphotactics of human languages is not regular but linear context-free.

required for these examples is that the *syntactic* constituent X in the schema be analyzed as X-PLU(-POSS)-DAT, after N_0 *and* N_0 coordination.

What we need then is not a lexemic but a morphemic organization in which bracketing of free and bound morphemes are regulated in syntax. The lexicon, of course, must now supply the ingredients of a morphosyntactic calculus. This leads to a theory in which semantic composition parallels morphosyntactic combination by the virtue of bound morphemes being able to pick their domains just like words (above X_0, if needed). A comparison of English and Turkish in this regard is noteworthy. English relative pronouns *that/whom* and the Turkish relative participle *-diğ-i* would have exactly the same semantics when the latter is granted a representational status in the lexicon (see section 6).

Furthermore, rule-based PSGs project a rigid notion of surface constituency. Steedman (2000) argued however that syntactic processes such as identical element deletion under coordination call for flexible constituency, such as SO (subject-object) in the SVO & SO gapping pattern of English, and SV constituency in the OSV & SV pattern of Turkish. Nontraditional constituents are also needed in specifying semantically transparent constituency of words, affixes, clitics and phrases.

Constraint-based PSGs such as HPSG appeal to coindexation and feature passing via unification to deal with such processes, rather than movement. HPSG also makes the commitment that inflectional morphology is internal to the lexicon, handled either by lexical rules (Pollard and Sag, 1994) or by lexical inheritance (Miller and Sag, 1997). We look at (5c) to highlight a problem with the stem-and-inflections view. As words enter syntax fully inflected, the sign of the verb *ver-diğ-i* in the relative clause (5c) would be as in (6a) in which the SUBCAT list of the verb stem is, as specified in the lexical entry for *ver*, unsaturated. The participle adds coindexation in MOD$|\cdots|$INDEX. The HPSG analysis of this example would be as in Figure 1. However, although passing the agreement features of the head separately (Sehitoglu, 1996) solves the case problem alluded to in (5c), structure-sharing of the NP_{dat} with the SLASH, INDEX and CONTENT features of *ver-diğ-i* is needed for semantics (GIVEE), but this conflicts with the head features of the topmost NP_{acc} in the tree. The relative participle as a lexical entry, e.g. (6b), would resolve the problem with subcategorization because its SUBCAT list is empty (like the relative pronoun *that* in English) hence there would be no indirect dependence of the nonlocal SLASH feature and the local SUBCAT feature via semantics (CONTENT). Such morphemic alternatives are not considered in HPSG, however, and require a significant revision in the theory. Furthermore, HPSG's lexical assignment for trace introduces phonologically null elements to the lexicon, which, as we show later, is not necessary.

(6) a. ver-diğ-i :=

$$\begin{bmatrix} \text{LOCAL} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{AGR} & \begin{bmatrix}\text{PERSON} & \textit{third}\\ \text{NUMBER} & \textit{sing}\end{bmatrix} \\ \text{CASE} & \textit{dat}\end{bmatrix} \\ \text{SUBCAT} & \langle \boxed{3}\,\text{NP[gen]}, \boxed{2}\,\text{NP[acc]}, \boxed{1}\,\text{NP[dat]}\rangle \\ \text{MOD | MODSYN | LOCAL | CONT | INDEX} & \boxed{1}\end{bmatrix} \\ \text{CONTENT} & \begin{bmatrix}\text{RELN} & \textit{give}\\ \text{GIVER} & \boxed{3}\\ \text{GIVEE} & \boxed{1} \\ \text{GIFT} & \boxed{2}\end{bmatrix}\end{bmatrix} \\ \text{NONLOCAL | TO-BIND | SLASH} & \{\boxed{1}\}\end{bmatrix}$$

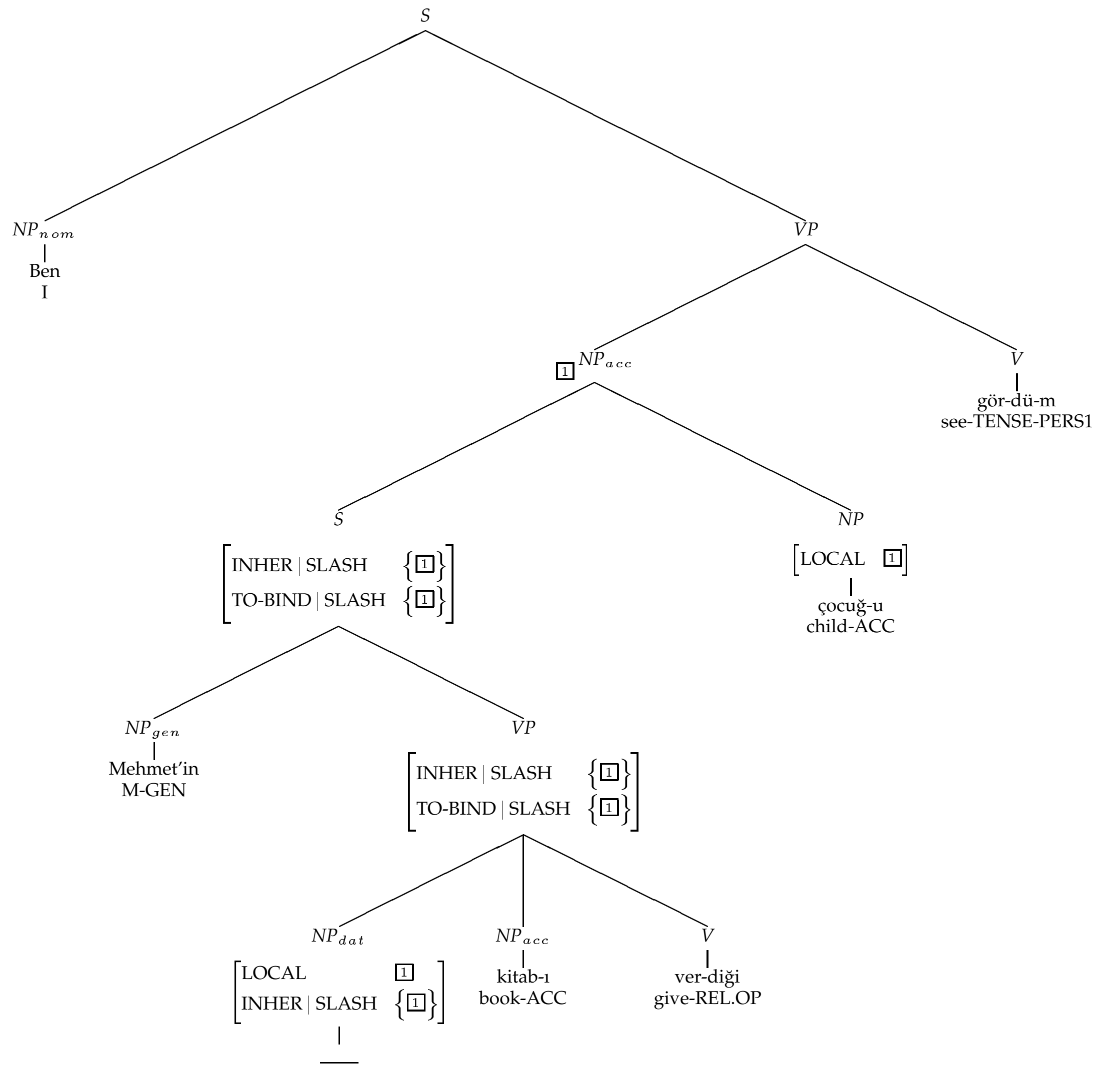


Figure 1
HPSG analysis of (5c).

b. -diğ-i := $\begin{bmatrix} \text{LOCAL} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \textit{noun}\begin{bmatrix}\text{acc or dat}\end{bmatrix} \\ \text{SUBCAT} & <> \end{bmatrix} \\ \text{CONTENT} & \textit{npro}\begin{bmatrix}\text{INDEX} & \boxed{1}\end{bmatrix} \end{bmatrix} \\ \text{NONLOCAL} \mid \text{INHER} \mid \text{SLASH} & \left\{\boxed{1}\right\} \end{bmatrix}$

Multimodal Categorial Grammars (Hepple, 1990a; Morrill, 1994; Moortgart and Oehrle, 1994) allow different modes of combination in the grammar. In addition to binary modes such as wrapping and commutative operations, unary modalities provide finer control over the categories. Heylen (1997; 1999) uses unary modalities as a way of regulating morphosyntactic features such as case, number, person for economy in lexical assignments. For instance, *Frau* has the category $\Box_{\text{case}}\Box_{\text{fem}}\Box_{\text{sg}}\Box_{\text{3p}}\Box_{\text{decl}}N$ which underspecifies it for case and declension. Underspecification is dealt with in the grammar using inclusion postulates, e.g. (7). The interaction of different modalities are regulated by distribution postulates.

(7) $\dfrac{\Box_{\text{case}}\Gamma \vdash X}{\Box_{\text{nom}}\Gamma \vdash X} \quad \dfrac{\Box_{\text{case}}\Gamma \vdash X}{\Box_{\text{acc}}\Gamma \vdash X}$

Lexical assignments to inflected words carry unary modalities: *boys* has the type $\Box_{\text{pl}}N$, in contrast to $\Box_{\text{sg}}N$ for *boy*. Although such regulation of inflectional features successfully mediates e.g. subject-verb agreement or NP-internal case agreement (as in German), it is essentially word-based because type assignments are to inflected forms; morphemes do not carry types. This reliance on word types necessitates a lexical rule-based approach to some morphosyntactic processes that create indefinitely long words, such as *-ki* relativization in Turkish (see section 6.5). But lexical rules for such processes risk nontermination (Sehitoglu and Bozsahin, 1999). Our main point of departure from MCG accounts is the morphemic vs. lexemic nature of the lexicon: The morphosyntactic and attachment modalities originate from the lexicon; they are not properties of the grammar (we elaborate more on this later). This paves the way to the morphemic lexicon by licensing type assignments to units smaller than words.

Besides problems with lexical rules, the automata-theoretic power of MCGs is problematic: Unrestricted use of structural modalities and postulates lead to Turing completeness (Carpenter, 1999). Indeed, one of the identifiable fragments of Multimodal languages that is computationally tractable is Combinatory Categorial languages (Kruijff and Baldridge, 2000), which we adopt as the basis for this framework. We propose a morphosyntactic Combinatory Categorial Grammar (CCG) in which the grammar and the morphemic lexicon refers to morphosyntactic types rather than syntactic types. We first introduce the syntactic CCG in section 2. Morphosyntactic CCG is described in section 3. In section 4, we look at the computational aspects of the framework. We show its realization for some aspects of English (section 5) and Turkish (section 6).

2 Syntactic Types

Categorial Grammar is a theory of grammar in which the form-meaning relation is conceived as a transparent correspondence between the surface-syntactic and semantic combinatorics (Jacobson, 1996). A CCG sign can be represented as a triplet $\pi - \sigma{:}\,\mu$, where π is the prosodic element, σ is its syntactic type, and μ its semantic type. For instance, the lexical assignment for read is (8).[3]

(8) read := *read* – $(S\backslash NP)/NP$: $\lambda x.\lambda y.\mathsf{read}\,xy$

Definition (Syntactic Types)

- The set of basic syntactic categories: $\mathcal{A}_s = \{N, NP, S, S_{\text{-t}}, S_{\text{+t}}\}$
- The set of complex syntactic categories: $\mathcal{B}_s$

— $\mathcal{A}_s \subseteq \mathcal{B}_s$

3 We take π to be the surface string for simplicity. We use the 'result-first' convention for CG. For instance, transitive verbs of English are written as $(S\backslash NP)/NP$, which translates to $(NP\backslash S)/NP$ in the 'result-on-top' convention.

— If $X \in \mathcal{B}_s$ and $Y \in \mathcal{B}_s$, then $X\backslash Y$ and $X/Y \in \mathcal{B}_s$

The classical Ajdukiewicz/Bar-Hillel (AB) Categorial Grammar is weakly equivalent to Context-free Grammars (Bar-Hillel, Gaifman, and Shamir, 1960). It has function application rules, defined originally in a nondirectional fashion. The directional variants and their associated semantics are:

(9) Forward Application (>):[4] $X/Y\!: f \quad Y\!: a \quad \Rightarrow \quad X\!: fa$
Backward Application (<): $Y\!: a \quad X\backslash Y\!: f \quad \Rightarrow \quad X\!: fa$

Combinatory Categorial Grammar (Steedman (1985; 1987; 1988); Szabolcsi (1983; 1987)) is an extended version of AB that includes function composition (10), substitution, and type raising (11). These extensions make CCGs mildly context sensitive.

(10) Forward Composition (>B): $X/Y\!: f \quad Y/Z\!: g \quad \Rightarrow \quad X/Z\!: \lambda x.f(gx)$
Backward Composition (<B): $Y\backslash Z\!: g \quad X\backslash Y\!: f \quad \Rightarrow \quad X\backslash Z\!: \lambda x.f(gx)$

(11) Forward Type Raising (>T):[5] $X\!: a \quad \Rightarrow \quad T/(T\backslash X)\!: \lambda f.f[a]$
Backward Type Raising (<T): $X\!: a \quad \Rightarrow \quad T\backslash(T/X)\!: \lambda f.f[a]$

Type raising is an order-preserving operation. For instance, Lambek's (1958) category *S/(S\NP)* is a positional encoding of the grammatical subject as a function looking for a VP (=*S\NP*) to the right to become *S*. The reversal of directionality such as topicalization (e.g., *This book, I recommend*) requires another schema. The reversal is with respect to the position of the verb, which we shall call **contraposition** and formulate as in (12).[6] (<XP) is leftward extraction of a right constituent, and (>XP) is rightward extraction of a left constituent, both of which are marked constructions. Directionally insensitive types such as *T|(T|X)* cause the collapse of directionality in surface grammar (Moortgart, 1988a).

(12) Leftward Contraposition (<XP): $X\!: a \quad \Rightarrow \quad S_{+t}/(S/X)\!: \lambda f.f[a]$
$S_{+t}/(S_{+t}/X)\!: \lambda f.f[a]$
Rightward Contraposition (>XP): $X\!: a \quad \Rightarrow \quad S_{-t}\backslash(S\backslash X)\!: \lambda f.f[a]$
$S_{-t}\backslash(S_{-t}\backslash X)\!: \lambda f.f[a]$

The semantics of contraposition depends on discourse properties as well. We leave this issue aside by (a) noting that it is related to type raising in changing the function-argument relation, (b) by categorizing the sentence as S_{+t} (topicalized) or S_{-t} (detopicalized), which are not discourse-equivalent to *S*. Syntactic characterization as such also helps a discourse component to do its work on syntactic derivations.

4 We omit the prosodic element for ease of exposition. For instance, the complete definition of forward application is $s_1 - X/Y\!: f \quad s_2 - Y\!: a \quad \Rightarrow \quad s_1 \bullet s_2 - X\!: fa$, where $\bullet$ is prosodic combination and fa is the application of f to a. The $\bullet$ will play a crucial role in the lexicalization of attachment later on.

5 The lambda term $f[a]$ denotes internal one-step β-reduction of f on a. In parsing, we achieve the same effect by partial execution (Pereira and Shieber, 1987). $\lambda f.f[a]$ is encoded as `(a^F)^F` in Prolog where ^ is lambda abstraction. We opted for the explicit $f[a]$ notation mainly for ease of exposition; cf. the semantics of raising verbs, relative participles, etc. in section 6. Moreover, as Pereira and Shieber noted, `(a^F)^F` is not a lambda term in strict sense because `a` is not a variable.

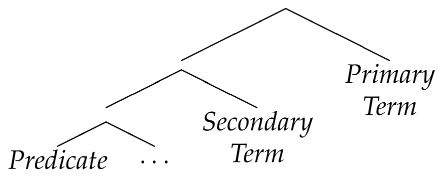
6 In fact, topicalization of nonperipheral arguments (*This book, I would give to Mary*), requires that (12) be finitely schematized over valencies, such as *S, S/NP, S/PP* (Steedman, 1985).

CCG's notion of interpretation is represented in the Predicate-Argument Structure (PAS). Its organization is crucial for our purposes since the bracketing in the PAS is the arbitrator for reconciling the bracketings in morphology and syntax via proper lexical type assignments. It is the sole level of representation in CCG (Steedman, 1996, p.89).[7] It is the level at which the conditions on objects of interpretation are formulated, such as binding and control. For instance, Steedman (1996) defines c-command and binding conditions A, B, C over the PAS. The PAS also reflects the obliqueness order of the arguments:

Predicate ... *Tertiary-Term Secondary-Term Primary-Term*

Assuming left-associativity for juxtaposition, this representation yields the bracketing in (13) for the PAS. Having the primary argument as the outermost term is motivated by the observations on binding asymmetries between subjects and complements in many languages (e.g., **Himself saw John, *heself*).

(13)



3 Morphosyntactic Types

A syntactic type such as N does not discriminate morphosyntactically. A finer distinction can be made as singular nouns, plural nouns, case-marked nouns etc. For instance, the set of number-marked nouns can be represented as $\overset{n}{\bowtie} N$ where $\bowtie$ is a morphosyntactic modality ('equals') and n is a diacritic (for *n*umber). *Books* is of type $\overset{n}{\bowtie} N$ but *book* is not. The type for *books* can be obtained morphosyntactically by assigning *-s* (-PLU) the functor type $\overset{n}{\bowtie} N \backslash \overset{b}{\bowtie} N$ where b stands for *b*ase. A syntactic type such as $N \backslash N$ overgenerates.

Another modality, $\triangleleft$ ('up to and equals'), allows wider domains in morphosyntactic typing. For instance, $\overset{n}{\triangleleft} N$ represents the set of nouns marked on number or any other diacritic that is lower than number in a partial order, e.g. Figure 2. The inflectional paradigm of a language can be represented as a partial ordering using the modalities.[8] For instance, if the paradigm is Base-Number-Case, we have $\upsilon(\overset{b}{\triangleleft} N) \subseteq \upsilon(\overset{n}{\triangleleft} N) \subseteq \upsilon(\overset{c}{\triangleleft} N)$ where $\upsilon(\tau)$ is the valuation function from the morphosyntactic type τ to the set of strings that have the type τ. The $\bowtie$ modality is more strict than $\triangleleft$ to provide finer control; although $\upsilon(\overset{n}{\triangleleft} N) \subseteq \upsilon(\overset{c}{\triangleleft} N)$, $\upsilon(\overset{n}{\bowtie} N) \not\subseteq \upsilon(\overset{c}{\bowtie} N)$, because a noun can be number-marked but not case-marked or vice versa. Also, $\upsilon(\overset{i}{\bowtie} N) \subseteq \upsilon(\overset{i}{\triangleleft} N)$ for any diacritic i since, for instance, the set of nouns marked up to and including case includes case-marked, number-marked, and unmarked nouns.

Lattice consistency condition is imposed on the set of diacritics to ensure category unity.[9] In other words, the syntactic type X can be viewed as an abbreviation for the

7 We will not elaborate on the theoretical consequences of having this level of representation; see for instance, Dowty (1991) and Steedman (1996).
8 see Heylen (1997) on use of unary modalities for a similar purpose in lexemic MCG.
9 In a lattice L, $x \leq y$ (morphosyntactically, $x \triangleleft y$) is equivalent to the consistency properties $x \wedge y = x$ and $x \vee y = y$. We use the join operator for this check, thus it suffices to have a join semilattice.

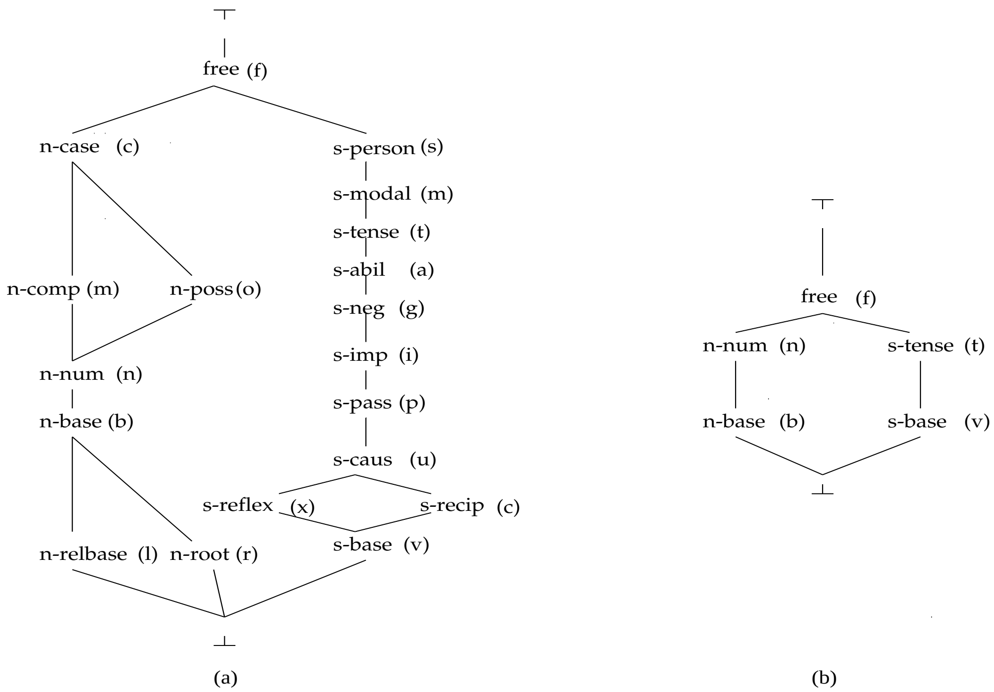


Figure 2
The lattice of diacritics for Turkish (a) and English (b).

morphosyntactic type $\overset{\top}{\triangleleft} X$ where $\top$ is the universal upper bound. It is the most under-specified category of X which subsumes all morphosyntactically decorated versions of X. Figure 2 shows the lattice for English and Turkish.

Definition (Morphosyntactic Types)

- $\mathcal{D}$= finite set of diacritics
- Join semilattice $L = (\mathcal{D}, \leq, =)$
- The set of basic morphosyntactic types: $\mathcal{A}_{ms}$

  — $\overset{i}{\triangleleft} X \in \mathcal{A}_{ms}$ and $\overset{i}{\bowtie} X \in \mathcal{A}_{ms}$ if $i \in \mathcal{D}$ and $X \in \mathcal{A}_s$ (see definition of syntactic types for $\mathcal{A}_s$)
  — ($\bowtie$ corresponds to lattice condition =)
  — ($\triangleleft$ corresponds to lattice condition $\leq$)

- The set of complex morphosyntactic types: $\mathcal{B}_{ms}$

  — $\mathcal{A}_{ms} \subseteq \mathcal{B}_{ms}$
  — If $X \in \mathcal{B}_{ms}$ and $Y \in \mathcal{B}_{ms}$, then $X\backslash Y$ and $X/Y \in \mathcal{B}_{ms}$

For instance, the infinitive marker *-ma* in (14a) can be lexically specified to look for untensed VPs—functions onto $\overset{a}{\triangleleft} S$—to yield a complex noun base (14b), which, as a consequence of nominalization (result type *N*), receives case to become an argument of the matrix verb. The adjective in *fake trucks* can be restricted to modify unmarked *N*s to get the bracketing [*fake truck*]-*s* (14c).

(14) a. *Mehmet* [[*kitab-ı* *oku*]-*ma*]-*yı* *istiyor*
M.NOM book-ACC read-INF-ACC wants
'Mehmet wants to read the book.'

b. -INF := *ma* – $\overset{b}{\triangleleft} N \backslash (\overset{a}{\triangleleft} S \backslash \overset{f}{\triangleleft} NP_{nom})$: $\lambda f.f$

c. fake := *fake* – $\overset{b}{\triangleleft} N / \overset{b}{\triangleleft} N$: $\lambda x.\textsf{fake}\; x$

Different attachment characteristics of words, affixes, and clitics must be factored in to the prosodic domain as a counterpart of refining the morphosyntactic description. In Montague Grammar, every syntactic rule is associated with a certain mode of attachment, and this tradition is followed in MCG; attachment types are related with the slash, e.g. $/_w$ for wrapping, which is a grammatical modality.[10] In the present framework, however, attachment is projected from the lexicon to the grammar as a prosodic property of the lexical items.[11] The grammar is unimodal in the sense that / and \ simply indicate the function-argument distinction in adjacent prosodic elements. The lexical projection of attachment further complements the notion of morphemic lexicon so that bound morphemes are no longer parasitic on words but have an independent representational status of their own. We write $\overset{i}{\circ} s$ to denote the attachment modality i (*a*ffixation, *s*yntactic concatenation, *c*liticization) of the prosodic element s.

Table 1 shows some lexical assignments for Turkish, e.g. the sign $\overset{a}{\circ} s - X \backslash Y : \mu$ characterizes a suffix. The morphosyntactic calculus of CCG is defined with the addition of morphosyntactic types and attachment modalities as follows (similarly, for other combinatory rules):

(15) Forward Application (>):

$$\frac{\overset{i}{\circ} s_1 - X / \overset{\alpha_1}{\Box_1} Y : f \qquad \overset{j}{\circ} s_2 - \overset{\alpha_2}{\Box_2} Y : a}{\overset{k}{\circ} (s_1 \overset{k}{\bullet} s_2) - X : fa} >$$

if $\alpha_2 \Box_1 \alpha_1$ in lattice L, for: $\Box_1, \Box_2 \in \{\bowtie, \triangleleft\}$, $\alpha_1, \alpha_2 \in \mathcal{D}$ in L, $i, j, k \in \{a, s, c\}$, $\overset{i}{\circ}\ \overset{j}{\circ} \vdash_a \overset{k}{\circ}$

Forward Composition (>B):

$$\frac{\overset{i}{\circ} s_1 - X / \overset{\alpha_1}{\Box_1} Y : f \qquad \overset{j}{\circ} s_2 - \overset{\alpha_2}{\Box_2} Y / Z : g}{\overset{k}{\circ} (s_1 \overset{k}{\bullet} s_2) - X / Z : \lambda x. f(gx)} >\mathbf{B}$$

if $\alpha_2 \Box_1 \alpha_1$ in lattice L, for: $\Box_1, \Box_2 \in \{\bowtie, \triangleleft\}$, $\alpha_1, \alpha_2 \in \mathcal{D}$ in L, $i, j, k \in \{a, s, c\}$, $\overset{i}{\circ}\ \overset{j}{\circ} \vdash_a \overset{k}{\circ}$

10 See Dowty (1996) and Steedman (1996) for a discussion on bringing nonconcatenative combination into grammar.

11 There is a precedent of associating attachment characteristics with the prosodic element rather than the slash in CG (Hoeksema and Janda, 1988). In their notation, arguments can be constrained on phonological properties and attachment. For instance, the English article *a* has its *NP/N* category spelled out as </CX/N,NP,Pref>, indicating a consonantal first segment for the noun argument, and concatenation to the left.

Table 1
Attachment properties of some Turkish morphemes.

uzun (long) :=	$\overset{s}{\circ}\ uzun\ -\ \overset{b}{\triangleleft}N/\overset{b}{\triangleleft}N$	*uzun* *yol* long road 'long road'
oku (read) :=	$\overset{s}{\circ}\ oku\ -\ \overset{v}{\triangleleft}S\backslash\overset{f}{\triangleleft}NP_{nom}\backslash\overset{f}{\triangleleft}NP_{acc}$	*adam* *kitab-ı* *oku-du* man book-ACC read-TENSE 'the man read the book.'
-EMPH :=	$\overset{c}{\circ}\ de\ -X\backslash X$	*Ben* *de* *yaz-ar-ım* I too write-TENSE-PERS 'I write too.'
-LOC :=	$\overset{a}{\circ}\ de\ -\ \overset{c}{\triangleleft}N\backslash\overset{o}{\triangleleft}N$	*Ben-de* *kalem* *var* I-LOC pen exist 'I have a pen.'

The main functor's argument specification ($\square_1$ of $\overset{\alpha_1}{\square_1}\ Y$ above) determines the lattice condition in derivations.[12] Hence the morphosyntactic decoration in lexical assignments propagate their lattice condition to grammar as in $\alpha_2\square_1\alpha_1$ (cf. Heylen (1997) where the grammar rule imposes a *fixed* partial order, e.g., X/Y combines with Z if $Z \leq Y$). This is another prerequisite for the morphemic lexicon to project the lexical specification of scope.

The grammar is not fixed on the attachment modality either (unlike a lexemic grammar, which is fixed on combination of words). Hence another requirement is the propagation of attachment to grammar. This is facilitated by the lexical types $\overset{m}{\circ}\ s-\sigma\colon\mu$ where m is an attachment type. The attachment calculus $\overset{i}{\circ}\ \overset{j}{\circ}\ \vdash_a\ \overset{k}{\circ}$ in (15), which reads attachment types i and j yield type k, relates attachment to prosodic combination in the grammar.[13] It can be attuned to language-particular properties.

We can specify some prosodic properties of the attachment calculus for Turkish as follows ($\acute{x}$ indicates stress on the prosodic element x):

syntactic concatenation	$\acute{x}\overset{s}{\bullet}\acute{y}$	=	$\acute{x}\acute{y}$
affixation	$\acute{x}\overset{a}{\bullet}y$	=	$x\acute{y}$
cliticization	$\acute{x}\overset{c}{\bullet}y$	=	$\acute{x}\acute{y}$

4 Morpheme-based Parsing

To contrast lexemic and morphemic processing, consider the Turkish example in (16a). We show some stages of the derivation to highlight prosodic combination ($\bullet$) as well. Every item in the top row is a lexical entry. Allomorphs, such as that of tense, have the same category in the lexicon (16b). Vowel harmony, voicing and other phonological

12 This coincides with Steedman's (1987) observation that directionality of the main functor's slash is also a property of the same argument. The main functor is the one whose result type determines the overall result type, i.e., X/Y in (15).

13 Clearly, much more needs to be done to incorporate intonation into the system. The motive for attachment types is to provide the representational ingredients on part of the morphemic lexicon. As a referee noted, CCG formulation of the syntax-phonology interface moved from autonomous prosodic types (Steedman, 1991) to syntax-directed prosodic features (Steedman, 2001). The present proposal for attachment modality is computationally compatible with both accounts: Combinatory prosody can match prosodic types with morphosyntactic types. Prosodic features are associated with basic categories of a syntactic type in the latter formulation, hence they become part of the featural inference that goes along with the matching of categories in the application of combinatory rules.

restrictions are handled as constraints on the prosodic element. Constraint checking can be switched off during parsing to obtain purely morphosyntactic derivations.

(16) a.

Can	Ayşe	nin	kitab	ı	oku	ması	nı	iste	di
C.NOM		-GEN(agr)	book	-ACC	read	-SUB1G	-ACC	want	-TENSE
$\overset{b}{\lhd} N$	$\overset{b}{\lhd} N$	$\overset{c}{\lhd} NP_{gen} \backslash \overset{o}{\lhd} N$	$\overset{b}{\lhd} N$	$\overset{c}{\lhd} N_{acc} \backslash \overset{o}{\lhd} N$	$\overset{v}{\lhd} S \backslash \overset{f}{\lhd} NP_{nom} \backslash \overset{f}{\lhd} NP_{acc}$	$\overset{o}{\lhd} N \backslash \overset{f}{\lhd} NP_{gen} \backslash (\overset{a}{\lhd} S \backslash \overset{f}{\lhd} NP_{nom})$	$\overset{c}{\lhd} N \backslash \overset{o}{\lhd} N$	TV	$(\overset{t}{\lhd} S \backslash \overset{f}{\lhd} NP) \backslash (\overset{a}{\lhd} S \backslash \overset{f}{\lhd} NP)$

$$\textit{iste} \overset{a}{\bullet} \textit{di} - \overset{t}{\lhd} S \backslash \overset{f}{\lhd} NP_{nom} \backslash \overset{f}{\lhd} NP_{acc}$$

$$\textit{kitab} \overset{a}{\bullet} \textit{ı} \overset{s}{\bullet} \textit{oku} - \overset{v}{\lhd} S \backslash \overset{f}{\lhd} NP_{nom}$$

$$(\textit{kitab} \overset{a}{\bullet} \textit{ı} \overset{s}{\bullet} \textit{oku}) \overset{a}{\bullet} \textit{ması} - \overset{o}{\lhd} N \backslash \overset{f}{\lhd} NP_{gen}$$

$$((\textit{ayşe} \overset{a}{\bullet} \textit{nin}) \overset{s}{\bullet} (\textit{kitab} \overset{a}{\bullet} \textit{ı} \overset{s}{\bullet} \textit{oku}) \overset{a}{\bullet} \textit{ması}) \overset{a}{\bullet} \textit{nı} - (\overset{t}{\lhd} S \backslash \overset{f}{\lhd} NP_{nom}) / (\overset{t}{\lhd} S \backslash \overset{f}{\lhd} NP_{nom} \backslash \overset{f}{\lhd} NP_{acc})$$

$$\textit{can} \overset{s}{\bullet} (\textit{ayşe} \overset{a}{\bullet} \textit{nin} \overset{s}{\bullet} \textit{kitab} \overset{a}{\bullet} \textit{ı} \overset{s}{\bullet} \textit{oku} \overset{a}{\bullet} \textit{ması} \overset{a}{\bullet} \textit{nı}) \overset{s}{\bullet} (\textit{iste} \overset{a}{\bullet} \textit{di}) - \overset{t}{\lhd} S$$

: want(read book ayse)can
'Can wanted Ayse to read the book.'

b. -TENSE := $\overset{a}{\circ}\, dı|di|du|dü|tı|ti|tu|tü - (\overset{t}{\lhd} S \backslash \overset{f}{\lhd} NP) \backslash (\overset{a}{\lhd} S \backslash \overset{f}{\lhd} NP) : \lambda f.f$

The lexicalization of attachment modality helps to determine the prosodic domain of postconditions. For instance, for Turkish, vowel harmony does not apply over word boundaries, which can be enforced by applying it when the modality is $\overset{a}{\circ}$ and $\overset{c}{\circ}$, but not $\overset{s}{\circ}$. Voicing applies to $\overset{a}{\circ}$ and $\overset{s}{\circ}$, but not to $\overset{c}{\circ}$.

The basic categories *N, NP, S*, S_{+t}, S_{-t} carry agreement features of fixed arity, e.g., tense and person for *S*, S_{+t}, S_{-t}; case, number, person, gender for *N* and *NP*. Positional encoding of such information as in (Pulman, 1996) allows efficient term unification for their propagation.[14] Term unification also handles the matching of complex categories in the CCG schema. For instance, $\overset{\alpha_1}{\Box_1} A/(\overset{\alpha_2}{\Box_2} B \backslash \overset{\alpha_3}{\Box_3} C)$ combines with $\overset{\beta_2}{\Box_4} B \backslash \overset{\beta_3}{\Box_5} C$ via (>) for $B, C \in \mathcal{A}_s$, if $\beta_2 \Box_2 \alpha_2$, $\beta_3 \Box_3 \alpha_3$ ($\Box_i \in \{\lhd, \bowtie\}$). Apart from the matching of syntactic types and agreement, unification does no linguistic work in this framework, in contrast to structure-sharing in HPSG and slash-passing in Unification CG (Calder, Klein, and Zeevat, 1988).

CCG is worst-case polynomially parsable (Vijay-Shanker and Weir, 1993). This result depends on the finite schematization of type raising, and bounded composition. Assuming a maximum valence of 4 in the lexicon (Steedman, 2000), composition (B^n) is bounded by $n \leq 3$. The refinement of the type raising schema (11) for finite schematization is shown in (17).

(17) a. Revised Forward Type Raising (>T): $NP : a \quad \Rightarrow \quad T/(T \backslash NP) : \lambda f.f[a]$

b. Revised Backward Type Raising (<T): $NP : a \quad \Rightarrow \quad T \backslash (T/NP) : \lambda f.f[a]$

$T \in \{S, S \backslash NP, S \backslash NP \backslash NP, S \backslash NP \backslash NP \backslash NP\}$.

14 Mediating agreement via unification, type subsumption or set-valued indeterminacy has important consequences on underspecification, the domain of agreement and the notion of 'like categories' in coordination; see (Johnson and Bayer, 1995; Dalrymple and Kaplan, 2000; Wechsler and Zlatić, 2000). Rather than providing an elaborate agreement system, we note that Pulman's techniques provide the mechanism for implementing agreement as atomic unification, subsumption hierarchies represented as lattices, or set-valued features. The categorial ingredient of phrase-internal agreement can be provided by endotypic functors when necessary (see sections 5 and 6).

The finite schematization of type raising suggests that it can be delegated to the lexicon, e.g., by a lexical rule that value-raises all functions onto *NP* to their type-raised variety, such as NP/N to $(S/(S\backslash NP))/N$. But this move presupposes the presence of such functions in the lexicon, i.e., a language with determiners. To be transparent with respect to the lexicon, we make type raising and other unary schema (contraposition) available in the grammar. Since both are finite schemas in the revised formulation, the complexity result of Vijay-Shanker and Weir still holds. Checking the lattice condition as in (15) incurs a constant factor with a finite lattice.

Type raising and composition cause the so-called 'spurious ambiguity' problem (Wittenburg, 1987): multiple analyses of semantically equivalent derivations are possible in parsing. This is shown to be desirable from the perspective of prosody, e.g., different bracketings are needed to match intonational phrasing with syntactic structure (Steedman, 1991). From the parsing perspective, the redundancy of analyses can be controlled by (a) grammar rewriting (Wittenburg, 1987), (b) checking the chart for PAS equivalence (Karttunen, 1989; Komagata, 1997), (c) making the processor parsimonious on using long-distance compositions (Pareschi and Steedman, 1987), or (d) parsing into normal forms (Eisner, 1996; Hepple, 1990b; Hepple and Morrill, 1989; König, 1989; Morrill, 1999). We adopt Eisner's method which eliminates chains of compositions in $O(1)$ time via tags in the grammar, before derivations are licensed. The switch can be turned off during parsing to obtain all surface bracketings. There is also a switch for checking the PAS equivalence, with the warning that checking the equivalence of two lambda expressions is undecidable.

The parser is an adaptation of Cocke-Kasami-Younger (CKY) algorithm (Aho and Ullman, 1972, p.315), modified to handle unary rules as well: In the kth iteration of the CKY algorithm to build constituents of length k, the unary rules apply to the CKY table entries $T[\alpha_i, \alpha_{i+k}], i = 0, 1, \ldots, n-k$, i.e. k-length results of binary rules are input to potential unary constituents of length k. In practice, this allows for instance to type-raise a nominalized clause after it is derived as a category of type *N*. The remaining combinatory schema is already in Chomsky Normal Form required by CKY. The finite schematization of CCG rules, and constant costs incurred by the normal form and lattice checking provide a straightforward extension of CKY-style context-free parsing for CCG. Komagata (1997) claims that the average complexity of CCG parsing is $O(n^3)$ even without the finite schematization of type raising (based on the parsing of 22 sentences consisting of around 20 words, with a lexicon of 200 entries and no derivation of semantics in the grammar; a morphological analyzer provided 5 analyses per second to the parser). Statistical techniques developed for lexicalized grammars, e.g., Collins (1997), readily apply to CCG to improve the average parsing performance in large scale practical applications (Hockenmaier, Bierner, and Baldridge, 2000). Both studies used section 02-21 of the WSJ Corpus of Penn Treebank for training, which contains 40,886 words (70,151 lexical entries). A recent initiative (Oflazer et al., 2001) aims to provide such a resource of around one million words for Turkish. It encodes in the Treebank surface syntactic relations and the morphological breakdown of words. The latter is invaluable for training morphemic grammars and lexicons.

In morpheme-based parsing, lattice conditions help eliminate the permutation problem in endotypic categories. Such categories are typical of inflectional morphemes. For instance, assume that three morphemes m_1, m_2, m_3 have endotypic categories (say $N\backslash N$), that they can appear only in this order, and that they are all optional. The categorization of m_i as $\overset{\kappa'_i}{\lhd} N\backslash \overset{\kappa_i}{\lhd} N$ such that $\kappa'_i \not\leq \kappa_i$ for all i, and $\kappa'_{j-1} \leq \kappa_j$ for $j = 1, 2, 3$ allows omissions (18a–b) but rules out the permutations (18c–d).[15]

(18) a.
$$\begin{array}{llll}
\textit{stem} & m_1 & m_2 & m_3\\
\overset{\kappa_0}{\triangleleft} N & \overset{\kappa_1'}{\triangleleft} N\backslash \overset{\kappa_1}{\triangleleft} N & \overset{\kappa_2'}{\triangleleft} N\backslash \overset{\kappa_2}{\triangleleft} N & \overset{\kappa_3'}{\triangleleft} N\backslash \overset{\kappa_3}{\triangleleft} N\\
\hline
\multicolumn{2}{l}{\overset{\kappa_1'}{\triangleleft} N \quad \text{because } \kappa_0 \le \kappa_1} & \multicolumn{2}{l}{<}\\
\hline
\multicolumn{3}{l}{\overset{\kappa_2'}{\triangleleft} N \quad \text{because } \kappa_1' \le \kappa_2} & <\\
\hline
\multicolumn{4}{l}{\overset{\kappa_3'}{\triangleleft} N \quad \text{because } \kappa_2' \le \kappa_3 \quad <}
\end{array}$$

b.
$$\begin{array}{ll}
\textit{stem} & m_3\\
\hline
\multicolumn{2}{l}{\overset{\kappa_3'}{\triangleleft} N \quad \text{because } \kappa_0 \le \kappa_3 \quad <}
\end{array}$$

c.
$$\begin{array}{llll}
{}^{*}\textit{stem} & m_2 & m_1 & m_3\\
\hline
\multicolumn{2}{l}{\overset{\kappa_2'}{\triangleleft} N \quad \text{because } \kappa_0 \le \kappa_2 \quad <} & &\\
\hline
\multicolumn{3}{l}{*** \quad <} &\\
\multicolumn{3}{l}{\kappa_2' \not\le \kappa_1 \quad \text{because } \kappa_1 < \kappa_1' \le \kappa_2 < \kappa_2'} &
\end{array}$$

d.
$$\begin{array}{llll}
{}^{*}\textit{stem} & m_1 & m_3 & m_2\\
\hline
\multicolumn{2}{l}{\overset{\kappa_1'}{\triangleleft} N \quad \text{because } \kappa_0 \le \kappa_1 \quad <} & &\\
\hline
\multicolumn{3}{l}{\overset{\kappa_3'}{\triangleleft} N \quad \text{because } \kappa_1' \le \kappa_3 \quad <} &\\
\hline
\multicolumn{4}{l}{*** \quad <}\\
\multicolumn{4}{l}{\kappa_3' \not\le \kappa_2 \quad \text{because } \kappa_2 < \kappa_2' \le \kappa_3 < \kappa_3'}
\end{array}$$

The lattice and its consistency condition on derivability offer varying degrees of flexibility. A lattice with only $\top$ and the relation $\le$ would undo all the effects of parametrization; it would be equivalent to a syntactic grammar in which every basic category X stands for $\overset{\top}{\triangleleft} X$. To enforce a completely lexemic syntax, a lattice with $\top$ and *free* would define all functional categories as functions over free forms.

Morphological processing seems inevitable for languages like Turkish, and morphological and lexical ambiguity such as (19) must be passed on to syntax irrespective of how inflectional morphology is processed (isolated from or integrated to syntax). For the verbal paradigm, Jurafsky and Martin (2000) reports Oflazer's estimation that inflectional suffixes alone create around 40,000 word forms per root. In the nominal paradigm, iterative processes such as *-ki* relativization (section 6.5) can create millions of word forms per nominal root (Hankamer, 1989).

(19) a. *kazma-ları*
pickaxe-POSS3p
'their pickaxe'

b. *kazma-lar-ı*
pickaxe-PLU-POSS3p
'their pickaxes'

15 Three stars in a line indicate that the derivation is not licensed.

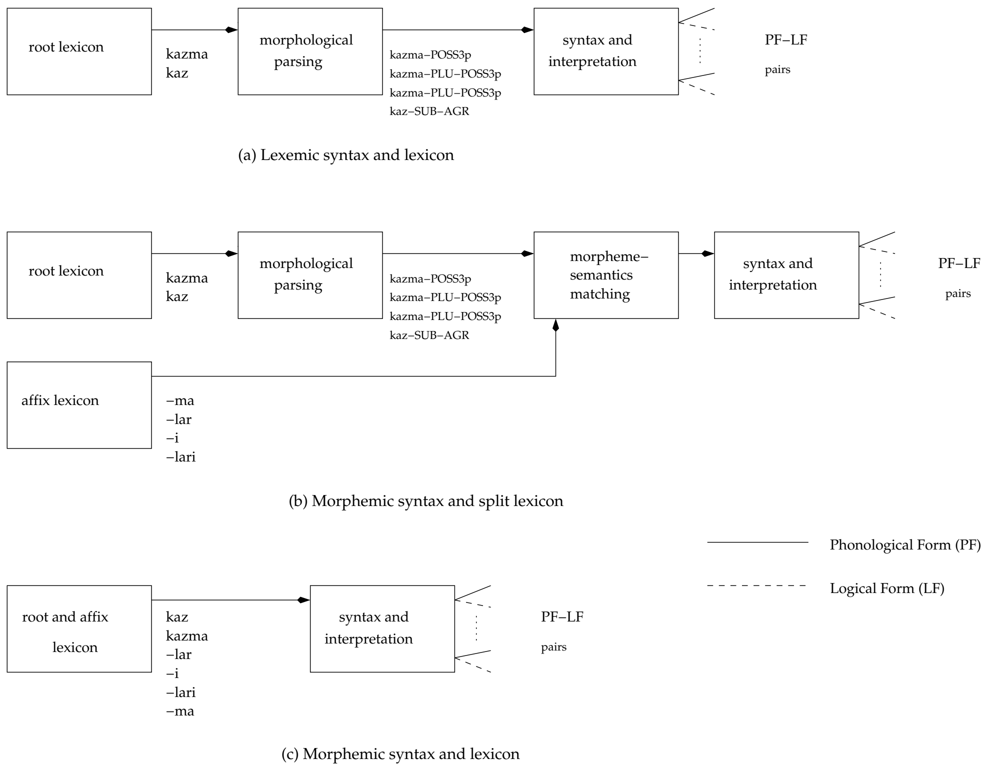


Figure 3
The processing of *kazmaları* in three different architectures (see example (19) for glosses).

c. *kazma-lar-ı*
pickaxe-PLU-POSS3s
'his/her pickaxes'

d. *kaz-ma-ları*
dig-SUB-AGR
'their digging'

The questions related to processing are (1) what a (super)linear fragment of processing for morphology should deliver to (morpho)syntax, and (2) whether the syntax is lexemic or morphemic. The problems with lexemic syntax, which stem from mismatches with semantics, were highlighted in the introduction. In other words, a lexemic grammar (e.g. Figure 3a) is computationally nontransparent when interpretation is a component of the NLP system.

Regarding the first question, let us consider two architectures from the perspective of the lexicon for the purpose of morphology, morphemic syntax, and semantics interface. The architecture in Figure 3b incorporates the current proposal as an interpretive front-end to a morphological analyzer such as Oflazer's (1994), which delivers the analyses of words as a stream of morphemes out of which the bound morphemes have to be matched with their semantics from the affix lexicon to be interpretable in grammar. The advantage of this model is its efficiency; morphological parsing of words is—in principle—linear context-free; hence, finite-state techniques and their computational advantages readily apply. But the uninterpretable surface forms of bound morphemes must match with the affix lexicon, and this is not necessarily a one-to-one mapping due

Table 2
Parsing performance (CPU times are for a Sun UltraSparc-4 running SICStus Prolog; lexical items include stems and inflectional affixes).

Sample text type	Number of items in text			Avg. number of parses/gram. input		Avg. CPU time per test (milliseconds)		
	tests	words	morphs	PAS check	NF parse	Unrestr.	PAS check	NF parse
Word order & case	58	216	384	1.26	3.68	39	39	30
Subordination	14	70	137	3.00	5.09	267	270	180
Relativization	23	130	232	2.04	2.32	796	783	266
Control verbs	33	147	291	1.42	3.34	166	163	137
Possessives & compounds	26	109	200	1.23	2.47	137	135	98
Adjuncts	14	57	100	1.12	4.87	89	88	72
-ki relatives	24	66	179	1.07	1.54	36	36	35

to multiple lexical assignments for capturing the syntactic-semantic distinctions, e.g. dative case as a direct object, indirect object, or adjunct marker; or *-i* as a possessive and/or compound marker. Surface form-semantics pairing is not a trivial task, particularly in the case of lexically composite affixes which require semantic composition as well as tokenization. The matching process needs to be aware of all the syntactic contexts in which certain affix sequences act as a unit, e.g. relative participles and agreement markers (*-diğ-i* relative participle as -OP-POSS or -OP-AGR), possessive and compound markers, etc. for Turkish. The factorization of syntactic issues into a morphological analyzer would also make the separate morphological component nonmodular, or expand its number of states to factor in these concerns, e.g. treating the -OP-POSS sequence as a state different than -OP followed by -POSS in which -POSS is not interpreted with the semantics of possession but that of agreement marking. Not knowing how much of the syntactic distinctions are handled by the morphological analyzer, a subsequent interpreter may need to reconsult the grammar if scoping problems arise.

The architecture in Figure 3c describes the current implementation of the proposal. Bound morphemes are fed to the parser along with their interpretation. This model is preferred over Figure 3b for its simplicity in the design and extendibility.[16] The price is lesser efficiency due to context-free processing of inflectional morphology. By one estimate (Oflazer, Gocmen, and Bozsahin, 1994), Turkish has around 59 inflectional morphemes out of a total of 166 bound morphemes, and Oflazer (personal communication) notes that the average number of bound morphemes per word in unrestricted corpora is around 2.8, including derivational affixes. In a news corpus of 850,000 words, the number of inflections per word is less than two (Oflazer et al., 2001). This is tolerable

16 The morphological analyzer would be in no better position to handle morpheme-semantics pairing if the architecture in Figure 3b were implemented with an integrated lexicon of roots and affixes. For instance, -POSS would still require distinct states due to the difference in the semantics of possession and agreement marking coming from the lexicon.

for sentences of moderate length in terms of the extra burden it puts on the context-free parser. Table 2 shows the results of our tests with the Prolog implementation of the system on different kinds of constructions. The test cases included 10 lexical items on the average, with an average parsing time of 0.32 seconds per sentence. A relatively long sentence (12 words, 21 morphemes) took 2.9 seconds to parse. The longest sentence (20 words, 37 morphemes) took 40 seconds. The lexicon for the experiment included 700 entries; 139 were free morphemes and 561 were bound morphemes compiled out of 105 allomorphic representations (including all the ambiguous interpretations of bound morphemes and the results of lexical rules). For a rough comparison with an existing NLP system with no disambiguation aids, Güngördü and Oflazer (1995) reported average parsing times of around 10 seconds per sentence for a lexicon of 24,000 free morphemes, and their morphological analyzer delivered around 2 analyses per second to a lexemic grammar. Oflazer's later (1996) morphological analyzer contained an abstract morphotactic component of around 50 states for inflections, which compiled out to 30,000 states and 100,000 transitions when the morphophonemic rules were added to the system.

In conclusion, we note that the current proposal for a morphemic lexicon and grammar is compatible with both a separate morphological component (Figure 3b) and syntax-integrated inflectional morphology (Figure 3c). The architecture in Figure 3b may in fact be more suitable for inflecting languages (e.g. Russian) in which the surface forms of bound morphemes are difficult to isolate (e.g. *méste*, locative singular of *mésto*) but can be delivered as a sequence of morpheme labels by a morphological analyzer (e.g. *mésto*-SING-LOC), to be matched with the lexical type assignments to -SING and -LOC for grammatical interpretation.

It might be argued that in computational models of type Figure 3b, the lattice is not necessary because the morphological analyzer embodies the tactical component. But not only tactical problems (cf. example (18) and its discussion) but transparent scoping in syntax and semantics is also regulated by the use of lattice in type assignments, and that is our main concern. We show examples of such cases in the remainder of the paper. Thus the nonredundant role of the lattice decouples the morphemic grammar-lexicon from the kind of morphological analysis performed in the back-end.

5 Case Study: The English Plural

In this section, we present a morphosyntactic treatment of the English plural morpheme. The lattice for English is shown in Figure 2b. We follow Carpenter (1997) in categorizing numerical modifiers and intersective adjectives as plural noun modifiers: *four boys* is interpreted as $\mathsf{four}(\mathsf{plu}\ \mathsf{boy})$, and *green boxes* as $\mathsf{green}(\mathsf{plu}\ \mathsf{box})$. This bracketing reflects the 'set of sets' interpretation of the plural noun; $\mathsf{four}(\mathsf{plu}\ \mathsf{boy})$ denotes the set of nonempty nonsingleton sets of boys with four members. The type assignments in (20) correctly interpret the interaction of the plural and these modifiers (cf. 21a–b). The endotypic category of the plural also allows phrase-internal number agreement for languages that require it; the agreement can be regulated over the category *N* before the specifier is applied to the noun group to obtain *NP*.

(20)

$$\begin{array}{lll} \text{-PLU} & := & \overset{a}{\circ} s - \overset{n}{\triangleleft} N \backslash \overset{b}{\triangleleft} N\colon \lambda x.\mathsf{plu}\ x \\ \text{four} & := & \overset{s}{\circ} \mathit{four} - \overset{n}{\triangleleft} N / \overset{n}{\bowtie} N\colon \lambda x.\mathsf{four}\ x \\ \text{green} & := & \overset{s}{\circ} \mathit{green} - \overset{n}{\triangleleft} N / \overset{n}{\triangleleft} N\colon \lambda x.\mathsf{green}\ x \end{array}$$

(21) a.

$$\begin{array}{ccc}
\textit{four} & \textit{boy} & \textit{-s} \\
\hline
\overset{n}{\triangleleft}N/\overset{n}{\bowtie}N & \overset{b}{\triangleleft}N & \overset{n}{\triangleleft}N\backslash\overset{b}{\triangleleft}N \\
 & \multicolumn{2}{c}{\overline{\overset{n}{\triangleleft}N\text{: }\mathsf{plu\ boy}}^{<}} \\
\multicolumn{3}{c}{\overline{\overset{n}{\triangleleft}N : \mathsf{four(plu\ boy)}}^{>}}
\end{array}$$

b.

$$\begin{array}{cc}
\textit{four}\quad\textit{boy} & \textit{-s} \\
\overline{\overset{n}{\triangleleft}N\text{: }\mathsf{four\ boy}}^{>\ ***} & \overline{\overset{n}{\triangleleft}N\backslash\overset{b}{\triangleleft}N} \\
\text{because n-base} \neq \text{n-num} & \\
\multicolumn{2}{c}{\overline{\overset{n}{\triangleleft}N\text{: * }\mathsf{plu(four\ boy)}}^{***}}
\end{array}$$

Carpenter (1997) points out that nonintersective adjectives (e.g, *toy, fake, alleged*) are unlike numerical modifiers and intersective adjectives in that their semantics require phrasal (wide) scope for -PLU, corresponding to the 'set of things' interpretation of the plural noun. Thus, *toy guns* is interpreted as plu(toy gun) because the plural outscopes the modification. It denotes a nonempty nonsingleton set of things that are not really guns but toy guns. *toy(plu gun) would interpret plu over guns. The situation is precisely the opposite of (21); we need the second derivational pattern to go through and the first one to fail. The following category for nonintersective adjectives derives the wide scope for -PLU but not the narrow scope:

(22) toy $:=$ $\overset{s}{\circ}\,\textit{toy} - \overset{b}{\triangleleft}N/\overset{b}{\triangleleft}N\text{: }\lambda x.\mathsf{toy}\ x$

(23) a.

$$\begin{array}{ccc}
\textit{toy} & \textit{gun} & \textit{-s} \\
\overline{\overset{b}{\triangleleft}N/\overset{b}{\triangleleft}N} & \multicolumn{2}{c}{\overline{\overset{n}{\triangleleft}N\text{: }\mathsf{plu\ gun}}^{<}} \\
\multicolumn{3}{c}{\overline{\overset{n}{\triangleleft}N : \mathsf{*toy(plu\ gun)}}^{***}} \\
\multicolumn{3}{c}{\text{because n-num} \not\leq \text{n-base}}
\end{array}$$

b.

$$\begin{array}{ccc}
\textit{toy} & \textit{gun} & \textit{-s} \\
\hline
\overset{b}{\triangleleft}N/\overset{b}{\triangleleft}N & \overset{b}{\triangleleft}N & \overset{n}{\triangleleft}N\backslash\overset{b}{\triangleleft}N \\
\multicolumn{2}{c}{\overline{\overset{b}{\triangleleft}N\text{: }\mathsf{toy\ gun}}^{>}} & \\
\multicolumn{3}{c}{\overline{\overset{n}{\triangleleft}N : \mathsf{plu(toy\ gun)}}^{<}}
\end{array}$$

Carpenter (1997) avoided rebracketing due to the plural by lexical type assignments to plural nouns and a phonologically null lexical entry to obtain different semantic effects of the plural. In our formulation, there is no lexical entry for inflected forms, and no phonologically null type assignment to account for the distinction in different types of plural modification; there is only one (phonologically realized) category for -PLU.[17] The modifiers differ only in the kind and degree of morphosyntactic control. Strict control ($\bowtie$) on *four* disallows *four boy*, and flexible control ($\triangleleft$) on *green* also handles *green box*. *Four green boxes* is interpreted as four(green(plu box)), not as *four(plu(green box)), and *four toy guns* is interpreted as four(plu(toy gun)), not as *plu(four(toy gun)). These derivations preserve the domain of the modifiers and the plural without rebracketing.

17 This is not to say that there is only one model-theoretic interpretation of plu. 'Sets of sets' and 'set of individuals' valuations of plu can be carried over the PAS.

6 Case Study: Turkish Morphosyntax

There have been several computational studies to model morphology-syntax interaction in Turkish. These unification-based approaches represent varying degrees of integration. Güngördü and Oflazer (1995) isolates morphology from syntax by having separate modules (a finite-state transducer for the former, and an LFG component for the latter), that is, the syntax is lexemic. The morphological component is expected to handle all aspects of morphology, including inflections and derivations. In Sehitoglu and Bozsahin (1999), lexical rules implement inflectional morphology, and derivations are assumed to take place in the lexicon. Hoffman's (1995) categorial analysis of Turkish is also lexemic; all lexical entries are fully inflected. Interpretive components of these systems face aforementioned difficulties due to their commitment to lexemic syntax. Inflectional morphology is incorporated into syntax in another categorial approach (Bozsahin and Göçmen, 1995) but morphotactic constraints are modeled with nonmonotonic unification, such as nonexistence checks for features, overrides, etc. The system cannot make finer distinctions in morphosyntactic types either. The result is an overgenerating and nontransparent integration of morphology and syntax due to the possibility of rebracketing and the unresolved representational basis of the lexicon.

In this section, we outline the application of the proposed framework to Turkish. We analyze a large fragment of the language, without any claims for a comprehensive grammar. The phenomena modeled here exhibit particular morphosyntactic problems described in the preceding sections. We assume the binding theory in Steedman (1996), which is predicated over the PAS. In each section, we provide a brief empirical observation about the phenomenon, propose lexical type assignments, exemplify derivations of the parser, and briefly discuss the constraints imposed by morphosyntactic types. Due to lack of space, we sometimes use abbreviated forms in derivations such as the genitive affix's $(N/(N\backslash N))\backslash N$ category for $(\overset{o}{\lhd} N/(\overset{o}{\bowtie} N_{pn}\backslash \overset{o}{\bowtie} N_{pn}))\backslash \overset{o}{\lhd} N_{pn}$, but the parser operates on full morphosyntactic representations.

6.1 Case Marking and Word Order

Turkish is regarded as a free constituent order language; all permutations of the predicate and its arguments are grammatical in main clauses, being subject to constraints on discourse and semantic properties such as definiteness and referentiality of the argument, and topic-focus distinctions. The mapping of surface functions to grammatical relations is mediated by case marking. Word order variation has lesser functionality in embedded clauses because of the fact that embedded arguments are less accessible to surface discourse functions like topic and focus. Embedded clauses are verb final.

6.1.1 Lexical Types We start with the lexical type assignments for the verbs. We use the abbreviations in (24a) when no confusion arises about the arguments' case or morphosyntactic type. Verb-final orders are regarded as basic, which suggests the category $S\backslash NP\backslash NP$ for transitive verbs. But Janeway (1990) argued that such underspecification for verb-peripheral languages causes undesirable ambiguity. Grammatical relations of the arguments are not determined by directionality but by case in such languages. The category $S\backslash NP_{nom}\backslash NP_{acc}$ resolves the ambiguity (24b–c).

(24) a. $IV =\quad S\backslash NP$
$TV =\quad S\backslash NP\backslash NP$
$DV =\quad S\backslash NP\backslash NP\backslash NP$

b. sev (like) := $\overset{s}{\circ}\ sev - \overset{v}{\lhd} S\backslash \overset{f}{\lhd} NP_{nom}\backslash \overset{f}{\lhd} NP_{acc}\colon \lambda x.\lambda y.\textsf{like}\, xy$

c. ver (give) := $\overset{s}{\circ}$ *ver* $-\ \overset{v}{\lhd} S\backslash \overset{f}{\lhd} NP_{nom}\backslash \overset{f}{\lhd} NP_{dat}\backslash \overset{f}{\lhd} NP_{acc}$: $\lambda x.\lambda y.\lambda z.\textsf{give}\, yxz$

d. $\overset{v}{\lhd} S\backslash \overset{f}{\lhd} NP_{nom}\backslash \overset{f}{\lhd} NP_{acc} : \lambda x.\lambda y.\textsf{like}\, xy \Rightarrow$
$\overset{v}{\lhd} S\backslash \overset{f}{\lhd} NP^{+ref}_{acc}\backslash \overset{f}{\lhd} NP_{nom} : \lambda y.\lambda x.\textsf{like}\, xy$

e. -ACC := $\overset{a}{\circ}$ *i|ı|u|ü|yi|yı|yu|yü* $-\ \overset{c}{\lhd} N_{acc}\backslash \overset{o}{\lhd} N$: $\lambda f.f$

f. -LOC := $\overset{a}{\circ}$ *de|da|te|ta* $-\ (\overset{\alpha}{\lhd} S/ \overset{\alpha}{\lhd} S)\backslash \overset{o}{\lhd} N$: $\lambda x.\lambda f.\textsf{at}\, fx$

Gapping behavior seems to indicate that Turkish is verb-final, not just SOV. SO and OS syntactic types must be distinguished to account for SO & SOV, OS & OSV, *SO & OSV and *OS & SOV. The OS & OSV pattern requires the lexical category $S\backslash NP_{acc}\backslash NP_{nom}$ for the verb (Bozsahin, 2000b). SOV and OSV base orders can be captured uniquely in the lexicon in set-CCG notation as $S\backslash\{NP_{acc}, NP_{nom}\}$. Set-CCG is strongly equivalent to CCG (Baldridge, 2000). However, we distinguish SOV and OSV lexically because OSV requires referential objects (25a–b). OSV is generated from SOV by a lexical rule (24d). This is genuine lexical ambiguity because the two related entries differ in semantics (referentiality).

(25) a. *Kitab-ı adam oku-du*
Book-ACC man.NOM read-TENSE
'the man read the book.'

b. **Kitap adam oku-du*
Book man.NOM read-TENSE

Regarding the relationship between case and the specifiers, it is questionable whether Turkish has a discernible syntactic category for determiners. There is no lexical functor that takes an *N* and yield an *NP*. The only article, the indefinite *bir ('a')*, makes a distinction in discourse properties (26). Specifying case as a determiner (e.g., $NP\backslash N$) does not alleviate the problem either. Ignoring the problem of case-stacking for a moment, zero marking of the surface subject and the indefinite object takes us back to where we started.

(26) *Çocuk yeşil bir elma/elma/elma-yı ye-miş*
child.NOM green an apple/apple/apple-ACC eat-TENSE
'The child ate a green apple.' (indefinite but referential apple)
'The child ate green apple.' (indefinite and nonreferential apple)
'The child ate the green apple.' (definite and referential apple)

Making the nouns lexically ambiguous (*N* or *NP*) would also require that all functions onto nouns be ambiguous ($N\backslash N$ and $NP\backslash NP$ for inflections, N/N and NP/NP for adjectives, etc.). Redundancy of this kind in the lexicon is not desirable since it is introduced purely for formal reasons with no distinction in meaning. We accommodate these concerns by positing a special case of type raising for Turkish (27). Similarly, contraposition turns *N*s into functors looking for *NP*s.

(27) Type Raising for Turkish: $N_{agr} : a \Rightarrow T/(T\backslash \overset{f}{\lhd} NP_{agr}): \lambda f.f[a]$
$\Rightarrow T\backslash(T/ \overset{f}{\lhd} NP_{agr}): \lambda f.f[a]$

$$T \in \{S, S\backslash NP, S\backslash NP\backslash NP, S\backslash NP\backslash NP\backslash NP\}$$

The noun that is type raised can be a syntactically derived noun (28). SO (and OS) constituency that is required for gapping is provided by $>\mathsf{T}$ and $>\mathsf{B}$.

(28)

Mehmet	*küçük yeşil kitab-ı,*	*çocuk da*	*yeni gelen dergi-yi*	*oku-du*
M.NOM	little green book-ACC	child-COORD	new come mag.-ACC	read-TENSE
N_{nom}	N_{acc}	N_{nom}	N_{acc}	$S\backslash NP_{nom}\backslash NP_{acc}$
$>\mathsf{T}$: $S/(S\backslash NP_{nom})$	$>\mathsf{T}$: $(S\backslash NP)/(S\backslash NP\backslash NP_{acc})$		⋮	

$>\mathsf{B}$: $S/(S\backslash NP_{nom}\backslash NP_{acc})$ (Mehmet küçük yeşil kitab-ı); $>\mathsf{B}$: $S/(S\backslash NP_{nom}\backslash NP_{acc})$ (çocuk da yeni gelen dergi-yi)

$\&$: $S/(S\backslash NP_{nom}\backslash NP_{acc})$

$>$: S

'Mehmet read the little green book, and the child, the newly arrived magazine'

Our lexical type assignment to case morphemes (24e–f) departs from other CCG analyses of case, e.g., (Steedman, 1985; Steedman, 1991; Bozsahin, 1998). These studies correlate morphological case with type raising of arguments, in the case of (Bozsahin, 1998), via a value-raised category assignment to case morphemes. Evidence from NP-internal case agreement and case-stacking (Kracht, 1999) challenges the type raising approach. Agreement phenomena require that case (which can be marked on articles, adjectives and the noun) be regulated as an agreement feature within the category N *before* the case-marked argument looks for the verb via type raising. Kracht observes that, in case-stacking, there may be other morphemes between two case morphemes. Thus, treating the two cases as composite affixes for the purpose of type raising is not feasible. If the first case type-raises the noun to say $T/(T\backslash NP)$, the second case would require the category e.g. $(T/(T\backslash NP))\backslash(T/(T\backslash NP))$, i.e., it is endotypic. Hence, an endotypic category for case (like other inflections in the paradigm) subsumes the type raising analysis of case provided that type raising is available in the grammar, not necessarily anchored to case.

We analyze case as an endotypic functor of type $N\backslash N$ (24e)—hence allow phrase-internal agreement for languages that require it, and provide type raising in grammar as in (27). Abandoning the type raising analysis of case does not necessitate taking liberties in the directionality of the categories, such as the use of nondirectional slash (|) in multiset-CCG (Hoffman, 1995). Contraposition and type raising in grammar can account for free word order and gapping facts with fully directional syntactic types (Bozsahin, 2000a).

6.1.2 Derivations Wide scope of case is captured by treating its argument type as non-case-marked N ($\overset{o}{\triangleleft} N$), and the type of noun modifiers as functions onto non-case-marked nouns of a particular domain, e.g. $\overset{b}{\triangleleft} N$ for nonintersective adjectives and $\overset{n}{\triangleleft} N$ for intersective adjectives (29a). The same strategy in type assignments to other nominal inflections allows them to outscope nominal modification, e.g. (29b).

(29) a.

Mehmet	[[*oyuncak*	*araba*]	*-lar*]	*-ı*	*sev-er*
M.NOM	toy	car	-PLU	-ACC	like-TENSE
$\overset{b}{\triangleleft} N_{nom}$	$\overset{b}{\triangleleft} N / \overset{b}{\triangleleft} N$	$\overset{b}{\triangleleft} N$	$\overset{n}{\triangleleft} N \backslash \overset{b}{\triangleleft} N$	$\overset{c}{\triangleleft} N_{acc} \backslash \overset{o}{\triangleleft} N$	$\overset{t}{\triangleleft} S \backslash \overset{f}{\triangleleft} NP_{nom} \backslash \overset{f}{\triangleleft} NP_{acc}$
: mehmet	: $\lambda x.$toy x	: car	: $\lambda x.$plu x	: $\lambda f.f$	: $\lambda x.\lambda y.$like xy

$>$T (Mehmet): $S/(S\backslash \overset{f}{\triangleleft} NP_{nom})$: $\lambda f.f$[mehmet]

$<$B (sev-er)

$>$: $\overset{b}{\triangleleft} N$: toy car

$<$: $\overset{n}{\triangleleft} N$: plu(toy car)

$<$: $\overset{c}{\triangleleft} N_{acc}$: plu(toy car)

$>$T: $(S\backslash NP)/(S\backslash NP\backslash \overset{f}{\triangleleft} NP_{acc})$: $\lambda g.g$[plu(toy car)]

$>$: $\overset{t}{\triangleleft} S\backslash \overset{f}{\triangleleft} NP_{nom}$: $\lambda y.$like(plu(toy car))y

$>$: S: like(plu(toy car))mehmet

'Mehmet likes toy cars.'

b. *Adam-ın* [*küçük kırmızı araba*]-*sı*
Man-GEN little red car-POSS
'The man's little red car' = poss(little(red car))man

A word-based alternative to reconcile semantic (wide) scope of inflections and their morphological (narrow) attachment to stems runs into difficulties even if we assume that morphemes carry type assignments—hence have representational status—but that they always combine with stems first. We use syntactic types to show the problem. If -PLU and -ACC in (29a) combine with the stem first, only the narrow scope reading of the plural and case is possible (30a). Plu(toy car) is not derivable with word-based modification. The morphosyntactic categories, however, are transparent to the scope of nominal modification, cf. (29a) and (30b).

(30) a.

oyuncak	[[*araba*]	*-lar*]	*-ı*
toy	car	-PLU	-ACC
N/N	N	$N\backslash N$	$N_{acc}\backslash N$
: $\lambda x.$toy x	: car	: $\lambda x.$plu x	: $\lambda f.f$

$<$: N: plu car

$<$: N_{acc}: plu car

$>$: N: $*$ toy(plu car)

b.

[*yeşil*	[*araba*]	*-lar*]	*-ı*
green	car	-PLU	-ACC
$\overset{n}{\triangleleft} N / \overset{n}{\triangleleft} N$	$\overset{b}{\triangleleft} N$	$\overset{n}{\triangleleft} N \backslash \overset{b}{\triangleleft} N$	$\overset{c}{\triangleleft} N_{acc} \backslash \overset{o}{\triangleleft} N$
: $\lambda x.$green x	: car	: $\lambda x.$plu x	: $\lambda f.f$

$<$: $\overset{n}{\triangleleft} N$: plu car

$>$: $\overset{n}{\triangleleft} N$: green(plu car)

$<$: $\overset{c}{\triangleleft} N_{acc}$: green(plu car)

Surface case annotations on categories enable the grammar to capture the correct PAS in all permutations of S, O and V while maintaining the discourse relevant distinctions (31). Enforcing verb-final subordinate clauses is accomplished by the directionality of the subordination morphemes in the lexicon.

(31) a.
$$\begin{array}{ccc}
\underline{\qquad\text{S}\qquad}_{>\mathrm{T}} & \underline{\qquad\text{O}\qquad}_{>\mathrm{T}} & \underline{\qquad\text{V}\qquad} \\
S/(S\backslash \overset{f}{\lhd} NP_{nom}) & (S\backslash NP)/(S\backslash NP\backslash \overset{f}{\lhd} NP_{acc}) & S\backslash NP_{nom}\backslash NP_{acc} \\
 & \multicolumn{2}{c}{\underline{\hspace{14em}}_{>}} \\
 & \multicolumn{2}{c}{S\backslash NP_{nom}} \\
\multicolumn{3}{c}{\underline{\hspace{24em}}_{>}} \\
\multicolumn{3}{c}{S}
\end{array}$$

b.
$$\begin{array}{ccc}
\underline{\qquad\text{O}\qquad}_{>\mathrm{T}} & \underline{\qquad\text{S}\qquad}_{>\mathrm{T}} & \underline{\qquad\text{V}\qquad} \\
S/(S\backslash \overset{f}{\lhd} NP_{acc}) & (S\backslash NP)/(S\backslash NP\backslash \overset{f}{\lhd} NP_{nom}) & S\backslash NP_{acc}\backslash NP_{nom} \\
 & \multicolumn{2}{c}{\underline{\hspace{14em}}_{>}} \\
 & \multicolumn{2}{c}{S\backslash NP_{acc}} \\
\multicolumn{3}{c}{\underline{\hspace{24em}}_{>}} \\
\multicolumn{3}{c}{S}
\end{array}$$

c.
$$\begin{array}{ccc}
\underline{\qquad\text{O}\qquad}_{>\mathrm{T}} & \underline{\qquad\text{V}\qquad} & \underline{\qquad\text{S}\qquad}_{>\mathrm{XP}} \\
(S\backslash NP)/(S\backslash NP\backslash \overset{f}{\lhd} NP_{acc}) & S\backslash NP_{nom}\backslash NP_{acc} & S_{\text{-t}}\backslash(S\backslash NP_{nom}) \\
\multicolumn{2}{c}{\underline{\hspace{14em}}_{>}} & \\
\multicolumn{2}{c}{S\backslash NP_{nom}} & \\
\multicolumn{3}{c}{\underline{\hspace{24em}}_{<}} \\
\multicolumn{3}{c}{S_{\text{-t}}}
\end{array}$$

d.
$$\begin{array}{ccc}
\underline{\qquad\text{S}\qquad}_{>\mathrm{T}} & \underline{\qquad\text{V}\qquad} & \underline{\qquad\text{O}\qquad}_{>\mathrm{XP}} \\
(S\backslash NP)/(S\backslash NP\backslash \overset{f}{\lhd} NP_{nom}) & S\backslash NP_{acc}\backslash NP_{nom} & S_{\text{-t}}\backslash(S\backslash NP_{acc}) \\
\multicolumn{2}{c}{\underline{\hspace{14em}}_{>}} & \\
\multicolumn{2}{c}{S\backslash NP_{acc}} & \\
\multicolumn{3}{c}{\underline{\hspace{24em}}_{<}} \\
\multicolumn{3}{c}{S_{\text{-t}}}
\end{array}$$

e.
$$\begin{array}{ccc}
\underline{\qquad\text{V}\qquad} & \underline{\qquad\text{S}\qquad}_{>\mathrm{XP}} & \underline{\qquad\text{O}\qquad}_{>\mathrm{XP}} \\
S\backslash NP_{nom}\backslash NP_{acc} & S_{\text{-t}}\backslash(S\backslash NP_{nom}) & S_{\text{-t}}\backslash(S_{\text{-t}}\backslash NP_{acc}) \\
\multicolumn{2}{c}{\underline{\hspace{14em}}_{<\mathrm{B}}} & \\
\multicolumn{2}{c}{S_{\text{-t}}\backslash NP_{acc}} & \\
\multicolumn{3}{c}{\underline{\hspace{22em}}_{<}} \\
\multicolumn{3}{c}{S_{\text{-t}}}
\end{array}$$

f.
$$\begin{array}{ccc}
\underline{\qquad\text{V}\qquad} & \underline{\qquad\text{O}\qquad}_{>\mathrm{XP}} & \underline{\qquad\text{S}\qquad}_{>\mathrm{XP}} \\
S\backslash NP_{acc}\backslash NP_{nom} & S_{\text{-t}}\backslash(S\backslash NP_{acc}) & S_{\text{-t}}\backslash(S_{\text{-t}}\backslash NP_{nom}) \\
\multicolumn{2}{c}{\underline{\hspace{14em}}_{<\mathrm{B}}} & \\
\multicolumn{2}{c}{S_{\text{-t}}\backslash NP_{nom}} & \\
\multicolumn{3}{c}{\underline{\hspace{22em}}_{<}} \\
\multicolumn{3}{c}{S_{\text{-t}}}
\end{array}$$

6.2 Subordination

Subordinate clauses can be classified as unmarked clauses (32a), infinitival clauses (32b), verbal nouns (32c), and nominalizations (32d). The latter two types require genitive embedded subject, which agrees with the subordinate verb.

(32) a. *Barış* [*çocuk* *ev-e* *git-ti*] *san-dı*
B.NOM child.NOM house-DAT go-TENSE assume-TENSE
'Barış assumed that the child went home.'

b. *Çocuk* [*kız-a* *kalem-i* *ver-me*] *-yi* *unut-tu*
child.NOM girl-DAT pen-ACC give-SUB1i -ACC forget-TENSE
'The child forgot to give the pen to the girl.'

c. [*Çocuğ-un araba-da uyu-ma-sı*] *Mehmet'i kız-dır-dı*
child-GEN car-LOC sleep-SUB1g-AGR M-ACC anger-CAUS-TENSE
'Child's sleeping in the car made Mehmet angry.'

d. *Güneş* [*çocuğ-un uyu-duğ-u*] *-na inan-m-ıyor*
G.NOM child-GEN sleep-SUB2g-AGR -DAT believe-NEG-TENSE
'Güneş does not believe the child's sleeping.'

(33) a. *Deniz*$_i$ [*kendisi-nin*$_i$ *uyu-ma-dığ-ı*]*-nı* *söyle-di*
D.NOM self-GEN sleep-NEG-SUB2g-AGR-ACC2 say-TENSE
'Deniz$_i$ said that he$_i$ did not sleep.'

b. **kendisi*$_i$ [*Deniz'in*$_i$ *uyu-ma-dığ-ı*]*-nı söyle-di*

c. *Deniz*$_i$ *adam-ı*$_j$ [*onun*$_{i/j}$ *uyu-duğ-u*]*-na* *inan-dır-dı*
D.NOM man-ACC him/her-GEN sleep-SUB2g-AGR-DAT2 believe-CAUS-TENSE
'Deniz$_i$ made the man$_i$ believe that he$_{i/j}$ slept.'

d. *Deniz*$_i$ *onu*$_{*i/*j}$ [*adam-ın*$_j$ *uyu-duğ-u*]*-na* *inan-dır-dı*
D.NOM him/her-ACC man-GEN sleep-SUB2g-AGR-DAT2 believe-CAUS-TENSE
'Deniz made him believe that the man slept.'

6.2.1 Lexical Types The asymmetries in (33) show that the obliqueness order in binding relations is preserved in subordination. This suggests the following bracketing in which the embedded clause's position in the PAS of the matrix predicate is determined by its grammatical function.

Matrix-Pred ...Matrix-Argument... Embedded-Clause... Matrix-Argument

(34) -SUB1i (-ma) (infinitive) := $\overset{a}{\circ}\ ma - \overset{b}{\lhd}N\backslash(\overset{a}{\lhd}S\backslash\overset{f}{\lhd}NP_{nom}): \lambda f.f$

-SUB1g (-ması) (verbal noun) := $\overset{a}{\circ}\ ması - \overset{o}{\lhd}N\backslash\overset{f}{\lhd}NP_{agr}\backslash(\overset{a}{\lhd}S\backslash\overset{f}{\lhd}NP_{nom}): \lambda f.f$

-SUB2g (-dığı) (nominalization) := $\overset{a}{\circ}\ dığı - \overset{o}{\lhd}N_{case=obl}\backslash\overset{f}{\lhd}NP_{agr}\backslash(\overset{a}{\lhd}S\backslash\overset{f}{\lhd}NP_{nom}): \lambda f.f$

The wide scope of case markers on subordinate clauses implies that the subordinate markers themselves must have phrasal scope as well. Since case is a nominal inflection, the category of a subordinate marker must be a function onto *N*. Its argument is *IV* for infinitives and $NP_{agr}\backslash IV$ for others, which require genitive subjects (34). This yields two families of functors for subordination. The verb-final characteristics of the embedded clauses is ensured by the backward-looking main functor of the subordinate marker.

For morphosyntactic modality, the resulting nominalized predicate can only receive case, hence it has $\overset{o}{\lhd}N$ control. Verbal nouns refer to actions, and nominalizations refer to facts. Subordinate markers for the former is tenseless. It replaces the tense of the subordinate verb in nominalizations, yielding $\overset{a}{\lhd}S$ control on the verb. For subject raising, the result may undergo any nominal inflection ($\overset{b}{\lhd}N$).

Word order variation within the subordinate clause is constrained by the subject on the left and the verb on the right. This is achieved by categorizing the embedded subjects as NP_{agr} and having a result category of *N* for all subordinate markers. If there were any contraposed element *NP* in the embedded clause, the category of the clause would be $S\backslash NP$, and the clause could not combine with the contraposed category such as $S_{\text{-t}}\backslash(S\backslash NP)$ on the right because the extraction category combines with a subordinate marker first, which is onto N, not $S\backslash NP$, hence composition (<B) could not take place.

6.2.2 Derivations Example (35a) is the derivation of subject raising (we use $N^{\uparrow}$ as an abbreviation for a type-raised N when space is limited). We use Steedman's (1996) ana function to denote the binding of the embedded subject. Infinitive -SUB1i has phrasal scope in this example; the DV must be reduced to an IV before the infinitive can apply. Hence the subordination of intransitive clauses is only a special case in which the morphological scope of the infinitive works without rebracketing. Subject raising and coindexation with the matrix subject are made explicit in the raising category of *unut*. The systematic relationship between the raised and nonraised category of such verbs can be captured by a lexical rule, e.g., TV: $\lambda x.\lambda y.\mathsf{forget}\,xy \Rightarrow TV$: $\lambda f.\lambda y.\mathsf{forget}(f[\mathsf{ana}\,y])y$.

(35b–c) contrast subject and nonsubject nominalizations. The difference is captured with the case distinction of the result type ($\overset{o}{\triangleleft}N$) for -SUB1g and -SUB2g. These examples also show the possibility of affix composition in the lexicon. For instance, we write *-masi* in (35b), which marks subordination and agreement together, instead of *-ma-si*. Otherwise, *-ma* (SUB1g) would have to look to the right as a functor to enforce agreement, and the verb-final property of subordination could not be assured.

(35) a.

$$\begin{array}{ccccccc}
\textit{Çocuk} & \textit{kız-a} & \textit{kalem-i} & \textit{ver} & \textit{-me} & \textit{-yi} & \textit{unut-tu}\\
\text{child.NOM} & \text{girl-DAT} & \text{pen-ACC} & \text{give} & \text{-SUB1i} & \text{-ACC} & \text{forgot}\\
\overline{N^{\uparrow}_{nom}}^{>T} & \overline{N^{\uparrow}_{dat}}^{>T} & \overline{N^{\uparrow}_{acc}}^{>T} & DV & \overset{b}{\triangleleft}N\backslash(\overset{a}{\triangleleft}S\backslash\overset{f}{\triangleleft}NP_{nom}) & \overset{c}{\triangleleft}N_{acc}\backslash\overset{o}{\triangleleft}N & \overline{TV}^{<B}\\
:\lambda f.f[\mathsf{child}] & :\lambda g.g[\mathsf{girl}] & :\lambda h.h[\mathsf{pen}] & :\lambda x.\lambda y.\lambda z.\mathsf{give}\,yxz & :\lambda f.f & :\lambda f.f & :\lambda f.\lambda x.\mathsf{forget}(f[\mathsf{ana}\,x])x
\end{array}$$

$$\begin{array}{ll}
\overset{v}{\triangleleft}S\backslash\overset{f}{\triangleleft}NP_{nom}\backslash\overset{f}{\triangleleft}NP_{dat} & >\\
\overset{v}{\triangleleft}S\backslash\overset{f}{\triangleleft}NP_{nom} & >\\
\overset{b}{\triangleleft}N & <\\
\overset{c}{\triangleleft}N_{acc} & <\\
(S\backslash NP)/(S\backslash NP\backslash\overset{f}{\triangleleft}NP_{acc}) & >T\\
\overset{t}{\triangleleft}S\backslash\overset{f}{\triangleleft}NP_{nom} & >\\
\overset{t}{\triangleleft}S: \mathsf{forget}(\mathsf{give\ girl\ pen}(\mathsf{ana\ child}))\mathsf{child} & >
\end{array}$$

'The child forgot to give the pen to the girl.'

b.

$$\begin{array}{ccccc}
\textit{Çocuğ-un} & \textit{uyu} & \textit{-ması} & \textit{Mehmet'i} & \textit{kızdır-dı}\\
\text{child-GEN} & \text{sleep} & \text{-SUB1g} & \text{M-ACC} & \text{anger-TENSE}\\
\overline{NP_{agr}}^{>T} & IV & N\backslash NP_{agr}\backslash IV & \overline{IV/TV}^{>T} & \overline{TV}^{<B}
\end{array}$$

$$\begin{array}{ll}
N\backslash NP_{agr} & <\\
IV & >\\
N & <\\
S/IV & >T\\
S: \mathsf{anger}(\mathsf{sleep\ child})\mathsf{mehmet} & >
\end{array}$$

'the child's sleeping angered Mehmet'

c. **Çocuğ-un uyu-duğu* *Mehmet'i kızdır-dı*
sleep-SUB2g

6.3 The Morphosyntax of Control

The control verb's controlled argument is marked by the infinitive *-ma*, and the resulting nominalized embedded clause can undergo nominal inflections (36a–b). The infinitive

-ma has the lexical type in (34). A potential conflict between an object-control verb's subcategorization and PAS is resolved by case decoration: *zorla 'force'* and *tavsiye et 'recommend'* differ in their case requirements and what is controlled (36b–c). *tavsiye et*'s infinitive complement is accusative whereas *zorla*'s is dative.

(36) a. *çocuk* [*kitab-ı* *oku-ma*]*-ya* *çalış-tı*
child.NOM book-ACC read-SUB1i-DAT try-TENSE
'The child$_i$ tried [to $\_\__i$ read the book]'

b. *Mehmet* *çocuğ-u* [*kitab-ı* *oku-ma*]*-ya* *zorla-dı*
M.NOM child-ACC book-ACC read-SUB1i-DAT force-TENSE
'Mehmet$_j$ forced the child$_i$ [to $\_\__{i/*j}$ read the book]'

c. *Mehmet* *çocuğ-a/*-u* [*kitab-ı* *oku-ma*]*-yı/*-ya* *tavsiye et-ti*
M.NOM child-DAT/ACC book-ACC read-SUB1i-ACC/DAT recommend-TENSE
'Mehmet recommended the child$_i$ [to $\_\__i$ read the book]'

6.3.1 Lexical Types Subject control verbs (e.g., *çalış* 'try'; *söz ver* 'promise') and object control verbs (e.g., *zorla*; *tavsiye et*) have this property indicated in their PAS (37). The nonraising variety of these verbs are obtained via a lexical rule.

(37)
çalış := $\overset{s}{\circ}$ *çalış* $-$ $TV\colon \lambda q.\lambda z.\mathsf{try}(q[\mathsf{ana}\,z])z$
söz ver := $\overset{s}{\circ}$ *söz ver* $-$ $DV\colon \lambda q.\lambda z.\lambda w.\mathsf{promise}\,z(q[\mathsf{ana}\,w])w$
zorla := $\overset{s}{\circ}$ *zorla* $-$ $DV\colon \lambda z.\lambda q.\lambda w.\mathsf{force}(q[\mathsf{ana}\,z])zw$
tavsiye et := $\overset{s}{\circ}$ *tavsiye et* $-$ $DV\colon \lambda z\lambda q\lambda w.\mathsf{recommend}(q[\mathsf{ana}\,z])zw$

6.3.2 Derivations These types, coupled with the raising category of the infinitive, yield the derivations in (38). These examples compose the infinitive complement before case can be applied on the nominalized predicate. This is possible due to the phrasal scope of *-ma* and the case markers. (38b) shows that although there may be two accusative-marked NPs, the arguments of the infinitive complement are identifiable; *IV* scope of *-ma* implies that any (di)transitive subordinate verb must find its nonsubject arguments before the matrix verb gets it's arguments. This type assignment strategy handles word order variations inside the infinitive complement and the matrix clause transparently.

(38) a.

$$\begin{array}{cccccc}
\textit{Çocuk} & \textit{kitab-ı} & \textit{oku} & \textit{-ma} & \textit{-ya} & \textit{çalış-tı} \\
\text{child.NOM} & \text{book-ACC} & \text{read} & \text{-SUB} & \text{-DAT} & \text{try-TENSE} \\
\overline{S/IV}^{>T} & \overline{IV/TV}^{>T} & \overline{TV} & \overline{N\backslash IV} & \overline{N_{dat}\backslash N} & \overline{TV}^{<B} \\
 & \multicolumn{2}{c}{\overline{\quad IV \quad}^{>}} & & & \\
 & \multicolumn{3}{c}{\overline{\quad N \quad}^{<}} & & \\
 & \multicolumn{4}{c}{\overline{\quad N_{dat} \quad}^{<}} & \\
 & \multicolumn{4}{c}{\overline{\quad IV/TV \quad}^{>T}} & \\
 & \multicolumn{5}{c}{\overline{\quad IV \quad}^{>}} \\
\multicolumn{6}{c}{\overline{\quad S\colon \mathsf{try}(\mathsf{read}\,\mathsf{book}(\mathsf{ana}\,\mathsf{child}))\mathsf{child} \quad}^{>}}
\end{array}$$

'The child tried to read the book.'

b. *Mehmet çocuğ-u kitab-ı oku -ma -ya zorla-dı*
M.NOM child-ACC book-ACC read -SUB -DAT force-TENSE

$$\frac{}{S/IV}{>}\mathsf{T} \quad \frac{}{IV/TV}{>}\mathsf{T} \quad \frac{}{IV/TV}{>}\mathsf{T} \quad \frac{}{TV} \quad \frac{}{N\backslash IV} \quad \frac{}{N_{dat}\backslash N} \quad \frac{}{DV}{<}\mathsf{B}$$

$$\frac{IV/TV \quad TV}{IV}{>} \qquad \frac{IV \quad N\backslash IV}{N}{<} \qquad \frac{N \quad N_{dat}\backslash N}{N_{dat}}{<} \qquad \frac{N_{dat}}{TV/DV}{>}\mathsf{T} \qquad \frac{TV/DV \quad DV}{TV}{>} \qquad \frac{IV/TV \quad TV}{IV}{>} \qquad \frac{S/IV \quad IV}{S}{>}$$

S: $\mathsf{force}(\mathsf{read\ book}(\mathsf{ana\ child}))\mathsf{child\ mehmet}$
'Mehmet forced the child to read the book.'

6.4 Relativization

There are two strategies for forming relative clauses: subject participle strategy (SP), and the nonsubject participle strategy (OP). SP is realized by the affixes *-(y)An*, *-(y)AcAk* and *-mIş*, and OP by *-dIk-* and *-(y)AcAk-*. OP triggers agreement similar to that of possessive constructions between the subject and the predicate of the relative clause (39b).

(39) a. *kitab-ı oku-yan adam*
book-ACC read-SP man
'The man that read/reads the book'

b. *adam-ın oku-duğ-u kitap*
man-GEN(AGR) read-OP-POSS(AGR) book
'The book that the man read'

6.4.1 Lexical Types The categories in (40) make explicit the unbounded nature of relativization; type raising and composition can combine indefinitely large sequence of constituents onto *S\NP*.

(40) -SP := $\overset{a}{\circ}\ yan - (N^{\uparrow}/\overset{f}{\triangleleft}N)\backslash(\overset{a}{\triangleleft}S\backslash\overset{f}{\triangleleft}NP_{nom})$
$: \lambda P.\lambda x.\lambda Q.\mathsf{and}(Q[x])(P[x])$

-OP.AGR (argument) := $\overset{a}{\circ}\ d\imath\breve{g}\imath - (N^{\uparrow}/\overset{f}{\triangleleft}N)\backslash(\overset{a}{\triangleleft}S\backslash\overset{f}{\triangleleft}NP_{case=obl})$
$: \lambda P.\lambda x.\lambda Q.\mathsf{and}(Q[x])(P[x])$

-OP.AGR (adjunct) := $\overset{a}{\circ}\ d\imath\breve{g}\imath - (N^{\uparrow}/\overset{f}{\triangleleft}N)\backslash\overset{a}{\triangleleft}S$
$: \lambda P.\lambda x.\lambda Q.\mathsf{and}(Q[x])(\mathsf{at}(P[x])x)$

We present a formulation of relativization without any use of empty categories, traces, or movement. We follow the Montagovian treatment of relative clauses as noun restrictors of the semantic type $\lambda P.\lambda Q.\mathsf{and}(Q[x])(P[x])$ where P is the semantics of the relative clause, and Q is the semantics of the predicate taking the relativized noun (x) as the argument. Montagovian analysis assumes a generalized quantifier (GQ) category for the determiner, i.e., *NP* is the functor and *VP* is the argument. The determiner takes the relativized noun (and its semantically type-raised category) as an argument as well. In a language with determiners, the functor category of the overall *NP* can be made explicit by lexically value-raising the determiner with GQ semantics from e.g. *NP/N* to *(S/(S\NP))/N = (S/VP)/N*. To achieve the same effect in a determinerless language, we make *NP* the functor by lexically value-raising the relative participle from *(N/N)\(S\NP)* to $(N^{\uparrow}/N)\backslash(S\backslash NP)$ in which $N^{\uparrow}/N$ denotes a value-raised noun since $N^{\uparrow}$ is a type-raised category. The category of the relative participle unfolds to $((S/(S\backslash NP))/N)\backslash(S\backslash NP)$ and $(((S\backslash NP)/(S\backslash NP\backslash NP))/N)\backslash(S\backslash NP)$.

Relativization is strictly head-final in Turkish. This implies that all relative participles are backward-looking functors which differ only in case requirements (cf. English relatives, which require different directionality, e.g., $(N\backslash N)/(S\backslash NP)$ for subjects and $(N\backslash N)/(S/NP)$ for nonsubjects). For morphosyntactic modality, the head noun has flexible control ($\overset{f}{\triangleleft} N$) because any further grammatical marking on the head must be shared (41).

(41) *Adam-ın gör-düğ-ü çocuk-lar uyu-du*
man-GEN see-OP-POSS child-PLU sleep-TENSE
'The children that the man saw slept.' = and(sleep(plu child))(see(plu child)man)
$\neq$*and(sleep(plu child))(see child man)

Morphologically, the agreement marker -POSS in OP strategy is a function over the -OP morpheme, but syntactically, the -OP morpheme triggers the agreement in the relative clause. Hence -OP-POSS can be treated as a lexically composite affix and glossed as -OP.AGR. This also assures the verb-final property of the relativized clause by not positing a rightward-looking functor for -OP. As for attachment modality, relative participles are bound morphemes which are affixed to the predicate.

6.4.2 Derivations (42a–d) show example derivations for subject, object, indirect object, and adjunct relativization. All nonsubject arguments are handled by a single -OP type (42b–c). Relativizing the specifier of an argument uses the same strategy as the argument. This phenomenon calls for another well-regulated lexical assignment schema, e.g., $(N^{\uparrow}/N)\backslash(N\backslash N)\backslash IV$ for the relativized specifier of the subject. (42e) is an example of relativizing the subject's specifier. Configurationality within the noun group is maintained by backward directionality of the categories.

(42) a. *kitab-ı oku -yan adam uyu-du*
book-ACC read -SP man sleep-TENSE

$\underline{\quad}_{>T}$ book-ACC: $IV/TV : \lambda f.f[book]$
read: $TV : \lambda x.\lambda y.\mathsf{read}\,xy$
-SP: $(N^{\uparrow}/N)\backslash IV : \lambda P.\lambda x.\lambda Q.\mathsf{and}(Q[x])(P[x])$
man: $N : \mathsf{man}$
$\underline{\quad}_{<B}$ sleep-TENSE: $IV : \lambda x.\mathsf{sleep}\,x$

$>$: $IV: \lambda y.\mathsf{read\ book}\,y$
$<$: $N^{\uparrow}/N: \lambda x.\lambda Q.\mathsf{and}(Q[x])(\mathsf{read\ book}\,x)$
$>$: $N^{\uparrow}{=}S/(S\backslash NP): \lambda Q.\mathsf{and}(Q[\mathsf{man}])(\mathsf{read\ book\ man})$
$>$: $S: \mathsf{and}(\mathsf{sleep\ man})(\mathsf{read\ book\ man})$
'The man that read the book slept.'

b. *adam-ın gör -düğü çocuk uyu-du*
man-GEN read -OP.AGR child sleep-TENSE

$\underline{\quad}_{<}$ man-GEN: NP_{agr}
read: TV
-OP.AGR: $(N^{\uparrow}/N)\backslash IV_{agr}$
child: N
$\underline{\quad}_{<B}$ sleep-TENSE: IV

$<$: IV_{agr}
$<$: $N^{\uparrow}/N$
$<$: $N^{\uparrow}{=}S/IV$
$>$: $S: \mathsf{and}(\mathsf{sleep\ child})(\mathsf{see\ child\ man})$
'The child that the man saw slept.'

c. *çocuğ-un* *kitab-ı* *ver* *-diği* *adam* *uyu-du*
child-GEN book-ACC give -OP.AGR man sleep-TENSE

NP_{agr} (<) TV/DV (>T) DV $(N^{\uparrow}/N)\backslash IV_{agr}$ N IV (<B)

TV (>)

IV_{agr} (<)

$N^{\uparrow}/N$ (<)

$N^{\uparrow}{=}S\backslash IV$ (>)

S: and(sleep man)(give man book child) (>)

'The man to whom the child gave the book slept.'

d. *çocuğ-un* *uyu* *-duğu* *araba* *bozul-du*
child-GEN sleep -OP.AGR car break-TENSE

NP_{agr} (<) IV $(N^{\uparrow}/N)\backslash S$ N IV (<B)

S (<)

$N^{\uparrow}/N$ (<)

$N^{\uparrow}{=}S/IV$ (>)

S: and(break car)(at(sleep child)car) (>)

'The car that the child slept in broke.'

e. *çocuğ* *-u* *uyu* *-yan* *adam* *kız-dı*
child -POSS sleep -SP man anger-TENSE

N $N\backslash N\backslash N$ IV $(N^{\uparrow}/N)\backslash(N\backslash N)\backslash IV$ N IV (<B)

$N\backslash N$ (<) $(N^{\uparrow}/N)\backslash(N\backslash N)$ (<)

$N^{\uparrow}/N$ (<)

$N^{\uparrow}{=}S/IV$ (>)

S: and(sleep(poss child man))(anger man) (>)

'the man whose child slept got angry.'

As these examples indicate, -SP and -OP do not range over the verb stem in semantic scope; they cover the entire relative clause. The wide scope of -SP and -OP resolves the inconsistency pointed out in the introduction (5b–c), which was mainly due to coindexation in unification accounts and the lexemic nature of the lexicon. Isolating the relative participle inflections in a morphological component undermines the transparency of derivations. Note also that -OP is categorially transparent to the arity of the verb; a *DV* must be reduced to an *IV* before -OP applies to the verb complex (42c). This is possible only when -OP has phrasal scope.

6.5 -ki Relativization

This is a morphosyntactic process which can generate indefinitely long words of relative pronouns and relative adjectives. *-ki* can be attached to case-marked nouns whose case relation is one of possession, time, or place (i.e., the genitive and the locative). Its effect is to create a nominal stem on which all inflections can start again (43a–b). It produces relative pronouns (43c) and relative adjectives (43d) with the locative, and only relative pronouns with the genitive.

(43) a. *araba-da-ki*
car-LOC-REL
'the one in the car'

b. *çocuğ-un ev-i-nde-ki-ler-in-ki*
child-GEN house-POSS-LOC2-REL-PLU-GEN-REL
lit. 'The one that belongs to the ones that are in the child's house'

c. *Ben ev-de-ki-ni hiç kullan-ma-dı-m*
I.NOM house-LOC-REL-ACC2 never use-NEG-TENSE-PERS.1s
'I never used the one at home.'

d. *ev-de-ki hediye*
house-LOC-REL present
'the present$_i$, the one$_i$ at home'

6.5.1 Lexical Types

(44)	a.	-PROki (locative)	:=	$\overset{a}{\circ}\ ki - \overset{l}{\bowtie} N \backslash \overset{c}{\bowtie} N_{loc} \colon \lambda x.\lambda f.\textsf{and}(\textsf{at}\,\textsf{PRO}\,x)(f[\textsf{PRO}])$
	b.	-ADJki	:=	$\overset{a}{\circ}\ ki - (\overset{l}{\bowtie} N / \overset{n}{\triangleleft} N) \backslash \overset{c}{\bowtie} N_{loc} \colon \lambda x.\lambda y.\lambda f.\textsf{and}(\textsf{at}\,xy)(f[y])$
	c.	-PROki (genitive)	:=	$\overset{a}{\circ}\ ki - \overset{l}{\bowtie} N \backslash N^{\uparrow}_{gen} \colon \lambda x.\lambda f.\textsf{and}(\textsf{poss}\,\textsf{PRO}\,x)(f[\textsf{PRO}])$
	d.	sabahki	:=	$\overset{s}{\circ}\ sabahki - \overset{l}{\bowtie} N / \overset{n}{\triangleleft} N \colon \lambda x.\lambda f.\textsf{and}(\textsf{at}\,\textsf{morning}\,x)(f[x])$
	e.	ki (that)	:=	$\overset{c}{\circ}\ ki - (N^{\uparrow} \backslash \overset{f}{\triangleleft} N)/(\overset{v}{\triangleleft} S \backslash \overset{f}{\triangleleft} NP_{nom})$ $\colon \lambda P.\lambda x.\lambda Q.\textsf{and}(Q[x])(P[x])$

$N^{\uparrow}_{gen}$ is a shorthand for the $N/(N\backslash N)$ category of a type raised genitive. In (43c), pronominal *one* (PRO) cannot be bound to *ev* (44a). Adjectival interpretation (43d) associates the relative adjective with the relativized noun (44b). For morphosyntactic modality, *ki*-marked nouns behave like possesive-marked nouns in case marking, which requires strict control over the possessive ($\overset{o}{\bowtie} N$). This presents a dilemma: morphologically, *-ki* creates a nominal stem that can undergo all nominal inflections again, but, as (45a) indicates, the stem does not take CASE (ACC, DAT, etc.) that is common to nouns unmarked on the possessive. Thus CASE2 in (45c) must refer to another diacritic (n-relbase, or $\overset{l}{\bowtie}$) to eliminate (45b). This diacritic controls the result category of *-ki*. The value-raised varieties of (44a–c) are assigned a type similar to the type of relative participles. Inherently temporal nouns such as *sabah ('morning')* can take *-ki* without the locative. They can be lexicalized without overgeneration with the help of the morphosyntactic modality $\overset{l}{\bowtie}$ (44d).

(45) a. **ev-de-ki-yi*
house-LOC-REL-ACC

b. **ev-ni*
house-ACC2

c. *ev-de-ki-ni*
house-LOC-REL-ACC2

d. *ev-i*
house-ACC

6.5.2 Derivations *-ki* ranges over the case-marked noun, which, as (46a–b) indicate, can be lexical or phrasal. In a lexemic analysis, the entire *ki*-marked noun would have to be rebracketed before the adjective *küçük* can apply to its right scope (which is *ev*, not *çocuk*).

(46) a. *ev* *-de* *-ki*
house -LOC -PROki

$$\begin{array}{lll}
\overset{b}{\triangleleft}N & \overset{c}{\triangleleft}N\backslash\overset{o}{\triangleleft}N & \overset{l}{\bowtie}N\backslash\overset{c}{\bowtie}N_{loc} \\
\hline
\multicolumn{2}{c}{\overset{c}{\triangleleft}N_{loc}} \; < & \\
\hline
\multicolumn{3}{l}{\overset{l}{\bowtie}N\colon \lambda f.\mathsf{and}(\mathsf{at\ PRO\ house})(f[\mathsf{PRO}]) \; <}
\end{array}$$

'The one that is in the house'

b. *küçük* *ev* *-de* *-ki* *çocuk*
little house -LOC -ADJki child

$$\begin{array}{lllll}
\overset{b}{\triangleleft}N/\overset{b}{\triangleleft}N & \overset{b}{\triangleleft}N & \overset{c}{\triangleleft}N\backslash\overset{o}{\triangleleft}N & (\overset{l}{\bowtie}N/\overset{n}{\triangleleft}N)\backslash\overset{c}{\bowtie}N_{loc} & \overset{b}{\triangleleft}N \\
\hline
\multicolumn{2}{c}{\overset{b}{\triangleleft}N} \; > & & & \\
\hline
\multicolumn{3}{c}{\overset{c}{\triangleleft}N_{loc}} \; < & & \\
\hline
\multicolumn{4}{c}{\overset{l}{\bowtie}N/\overset{n}{\triangleleft}N} \; < & \\
\hline
\multicolumn{5}{l}{\overset{l}{\bowtie}N\colon \lambda f.\mathsf{and}(\mathsf{at}(\mathsf{little\ house})\mathsf{child})(f[\mathsf{child}]) \; >}
\end{array}$$

'The child$_i$, the one$_i$ at the little house'

There is another *ki* in Turkish which forms nonrestrictive relative clauses as post-modifiers. It is a Persian borrowing and follows the Indo-European pattern of relative clause formation (47). It can be distinguished from the bound morpheme *-ki* lexically. Its attachment characteristic is also different than that of *-ki* (44e).

(47) *Adam ki hep uyur*
man that always sleep-TENSE
'the man, who always sleeps'

6.6 Possessive Constructions and Syntactic Compounds

The grammatical marking of possession is realized by the genitive case on the possessor (N_{gen}) and the possessive marker on the possessee (N_{poss}). N_{gen} and N_{poss} must agree on person and number (48a), and the resulting noun group is configurational. Possessives can be nested (48c).

(48) a. *ev-in kapı-sı*
house-GEN3 door-POSS3s
'the door of the house'

b. * *ev-in kapı* / **ev-in kapı-lar* (door-PLU)

c. *ben-im arkadaş-ım-ın ev-i-nin kapı-lar-ı*
I-GEN1 friend-POSS1s-GEN3 house-POSS3s door-PLU-POSS3s
'my friend's house's doors'

d. *ben-im arkadaş-ım-ın*$_i$ *dost-u-nun*$_j$ *kendisi*$_{*i/j}$
I-GEN1 friend-POSS1s-GEN3 buddy-POSS3s-GEN3 self
'my friend's buddy himself'

e. *Her çalışan-ın bazı hak-lar-ı vardır*
every worker-GEN3 some right-PLU-POSS3s exists
$\forall x \exists y((worker(x) \wedge right(y)) \rightarrow has(x,y))$
but not $\exists y \forall x(right(y) \wedge (worker(x) \rightarrow has(x,y)))$

6.6.1 Lexical Types for Possessives Type assignments for the genitive and the possessive can be schematized over person (p) and number (n) features as in (49).

$$
\begin{array}{lll}
\text{(49)}\quad \text{-GEN}_{pn} & := & \overset{a}{\circ}\ s - (\overset{o}{\lhd} N/(\overset{o}{\bowtie} N_{pn}\backslash \overset{o}{\bowtie} N_{pn}))\backslash \overset{o}{\lhd} N_{pn} \colon \lambda x.\lambda y.\mathsf{poss}\, yx \\
\quad\quad\;\; \text{-POSS}_{pn} & := & \overset{a}{\circ}\ s - (\overset{o}{\bowtie} N_{pn}\backslash \overset{o}{\bowtie} N_{pn})\backslash \overset{n}{\lhd} N_{pn} \colon \lambda f.f
\end{array}
$$

The possessive marker is a functor because it enforces agreement with the type raised specifier.[18] (48d–e) indicate that the genitive marker is a type-raiser; the possessor scopes over the possessee. For morphosyntactic modality, the genitive marker can be attached to nouns which are inflected up to and including a possessive marker ($\overset{o}{\lhd} N$). Moreover, nesting in possessives implies that the specifier may be a genitive. Hence, the stem's category must be $\overset{o}{\lhd} N$.

But there is a finer control over the possessee argument's category because it *must* be inflected with the possessive marker to signify relation of possession (cf. (48a–b)). Semantically, the possessive must outscope nominal modification. For instance, (50a) has the PAS as indicated, hence both markers must range over a noun group, not just the stem. Binding relations require an organization of the type (poss possee possessor) (50b–c).

(50) a. *yaşlı adam-ın küçük kız-ı*
old man-GEN3 little daughter-POSS3s
'old man's little daughter' = $\mathsf{poss}(\mathsf{little\ daughter})(\mathsf{old\ man})$

b. *adam$_i$-ın kendi$_i$-si*
man-GEN self-POSS
'the man himself'

c. **kendi$_i$ adam$_i$-ı*

6.6.2 Derivation of Possessive Constructions Example (51) shows the wide scope of the genitive (51a) and nested genitives (51b).

(51) a.

$$
\begin{array}{cccccc}
\textit{yaşlı} & \textit{adam} & \textit{-ın} & \textit{küçük} & \textit{kız} & \textit{-ı} \\
\text{old} & \text{man} & \text{-GEN} & \text{little} & \text{daughter} & \text{-POSS} \\
\overline{\overset{b}{\lhd} N/\overset{b}{\lhd} N} & \overline{\overset{b}{\lhd} N} & \overline{\overset{o}{\lhd} N/(\overset{o}{\bowtie} N\backslash \overset{o}{\bowtie} N)\backslash \overset{o}{\lhd} N} & \overline{\overset{b}{\lhd} N/\overset{b}{\lhd} N} & \overline{\overset{b}{\lhd} N} & \overline{\overset{o}{\bowtie} N\backslash \overset{o}{\bowtie} N\backslash \overset{n}{\lhd} N} \\
\multicolumn{2}{c}{\overline{\qquad\qquad}{>}} & & \multicolumn{2}{c}{\overline{\qquad\qquad}{>}} & \\
\multicolumn{2}{c}{\overset{b}{\lhd} N} & & \multicolumn{2}{c}{\overset{b}{\lhd} N} & \\
\multicolumn{3}{c}{\overline{\qquad\qquad\qquad\qquad}{<}} & \multicolumn{3}{c}{\overline{\qquad\qquad\qquad\qquad}{<}} \\
\multicolumn{3}{c}{\overset{o}{\lhd} N/(\overset{o}{\bowtie} N\backslash \overset{o}{\bowtie} N)} & \multicolumn{3}{c}{\overset{o}{\bowtie} N\backslash \overset{o}{\bowtie} N} \\
\multicolumn{6}{c}{\overline{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad}{>}} \\
\multicolumn{6}{c}{\overset{o}{\lhd} N\colon \mathsf{poss}(\mathsf{little\ daughter})(\mathsf{old\ man})} \\
\multicolumn{6}{c}{\text{'old man's little daughter'}}
\end{array}
$$

18 An 'inert' category such as N may be motivated by the pro-drop phenomenon where the specifier may be dropped under pragmatically conditioned circumstances. But this analysis disregards the point that binding relations (hence semantics) still require the coindexation of the specifier with some overt referent, which can be inferred from the discourse. Such interface phenomenon seems to be better suited for handling by interactions in the components of a multidimensional grammar, rather than as a purely syntactic phenomenon.

b. *ben* *-im* *arkadaş* *-ım* *-ın* *ev* *-i*

$$
\begin{array}{ccccccc}
\text{I} & \text{-GEN} & \text{friend} & \text{-POSS} & \text{-GEN} & \text{house} & \text{-POSS} \\
\overline{N} & \overline{N/(N\backslash N)\backslash N} & \overline{N} & \overline{N\backslash N\backslash N} & \overline{N/(N\backslash N)\backslash N} & \overline{N} & \overline{N\backslash N\backslash N} \\
\multicolumn{2}{c}{\underline{\qquad\qquad\qquad}{<}} & \multicolumn{2}{c}{\underline{\qquad\qquad\qquad}{<}} & & \multicolumn{2}{c}{\underline{\qquad\qquad\qquad}{<}} \\
\multicolumn{2}{c}{N/(N\backslash N)} & \multicolumn{2}{c}{N\backslash N} & & \multicolumn{2}{c}{N\backslash N} \\
\multicolumn{4}{c}{\underline{\qquad\qquad\qquad\qquad\qquad\qquad}{>}} & & & \\
\multicolumn{4}{c}{N} & & & \\
\multicolumn{5}{c}{\underline{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad}{<}} & & \\
\multicolumn{5}{c}{N/(N\backslash N)} & & \\
\multicolumn{7}{c}{\underline{\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad}{>}} \\
\multicolumn{7}{c}{N\text{: poss house(poss friend i)}} \\
\multicolumn{7}{c}{\text{'My friend's house'}}
\end{array}
$$

6.6.3 Lexical Types for Compounds Syntactic compounds exhibit syntactic patterns similar to possessive constructions, but they signify semantic relations of a different kind. In what follows, we use the function comp to signify that the arguments in the PAS form a compound, but say nothing about the range of productivity of this function. Lexical semantics of the arguments and a qualia structure (Pustejovsky, 1991) may indicate its range of applicability. Lexical type assignments for compound markers are as in (52).

(52) -COMP := $\overset{a}{\circ}\, s - \overset{m}{\bowtie} N\backslash \overset{n}{\triangleleft} N\backslash \overset{b}{\bowtie} N\colon \lambda x.\lambda y.\mathsf{comp}\, xy$

-COMP2 (nested comp) := $\overset{a}{\circ}\, s - \overset{m}{\bowtie} N\backslash \overset{m}{\bowtie} N\backslash \overset{n}{\triangleleft} N\backslash \overset{b}{\bowtie} N\colon \lambda x.\lambda y.\lambda z.\mathsf{comp}(\mathsf{comp}\, xy)z$

Syntactic compounds are formed by compound markers that are attached to the head of the compound. For morphosyntactic modality, nonreferentiality of the head implies no inflection ($\overset{b}{\bowtie} N$) or modification (53a–b). The left component can be a noun group (53c) in which there is ambiguity in the scope of modification. This is regulated by typing e.g. the intersective adjectives ambiguous as noun modifiers ($\overset{n}{\triangleleft} N/\overset{n}{\triangleleft} N$) and compound modifiers ($\overset{m}{\bowtie} N/\overset{m}{\bowtie} N$).[19] The overall compound may only be inflected for case, see e.g. (53d) and (53e).

(53) a. *otobüs bilet-i*
bus ticket-COMP
'bus ticket'

b. **otobüs yeşil bilet-i*
green

c. *yeşil otobüs bilet-i*
green bus ticket-COMP
green(comp ticket bus)
or comp(ticket(green bus))

d. *otobüs bilet-i-ni*
ticket-COMP-ACC2

e. **otobüs bilet-i-si*
ticket-COMP-POSS

Compound markers serve the dual function of compounding and agreement in possessive constructions; double marking of the possessive is suppressed (cf. 54a–b). -COMP2 type assignment in (52) handles nested compounds.

(54) a. *banka-nın faiz oran-ı*
bank-GEN interest rate-COMP.POSS
'interest rate of the bank'

b. **banka-nın faiz oran-ı-sı*
rate-COMP-POSS

19 I am grateful to the anonymous referee, who proposed this alternative.

We claim that plural compounds are lexically composite functions in a similar vein. This claim has some empirical support from the lexicalization of *-leri* as a third person plural possessive marker; see (55b–c). It follows that *-leri* has the lexical types of -COMP and -COMP2 with plural and possessive composition: $\lambda x.\lambda y.\mathsf{plu}(\mathsf{comp}\ xy)$.

(55) a. *otobüs bilet-leri*
bus ticket-COMP.PLU
'bus tickets'

b. *onlar-ın ev-leri*
they-GEN3 house-POSS3p
'their house'

c. *onlar-ın ev-ler-i*
they-GEN3 house-PLU-POSS3s
'their houses'

6.6.4 Derivation of Compounds (56) exemplifies derivations with these type assignments. (56a–b) show that both narrow and wide scope of the modifier can be accounted for. (56c–d) show that the compound marker interacts with the possessive. Hence, it must carry both poss and comp in possessive constructions involving compounds. (56e–f) are examples of nested compounds. (56f–g) show the effect of strict control ($\overset{b}{\bowtie}N$) over the compound's head.

(56) a.

$$\begin{array}{cccc}
\textit{yeşil} & \textit{otobüs} & \textit{bilet} & \textit{-i}\\
\text{green} & \text{bus} & \text{ticket} & \text{-COMP}\\
\hline
\overset{n}{\triangleleft}N/\overset{n}{\triangleleft}N & \overset{b}{\triangleleft}N & \overset{b}{\triangleleft}N & \overset{m}{\bowtie}N\backslash\overset{n}{\triangleleft}N\backslash\overset{b}{\bowtie}N\\
\hline
\multicolumn{2}{c}{\overset{n}{\triangleleft}N\ (>)} & \multicolumn{2}{c}{\overset{m}{\bowtie}N\backslash\overset{n}{\triangleleft}N\ (<)}\\
\hline
\multicolumn{4}{c}{\overset{m}{\bowtie}N: \mathsf{comp\ ticket(green\ bus)}\ (<)}
\end{array}$$

b.

$$\begin{array}{ccc}
\textit{yeşil} & \textit{otobüs} & \textit{bilet -i}\\
\hline
\overset{m}{\bowtie}N/\overset{m}{\bowtie}N & \overset{b}{\triangleleft}N & \overset{m}{\bowtie}N\backslash\overset{n}{\triangleleft}N\ (<)\\
\hline
 & \multicolumn{2}{c}{\overset{m}{\bowtie}N\ (<)}\\
\hline
\multicolumn{3}{c}{\overset{m}{\bowtie}N: \mathsf{green(comp\ ticket\ bus)}\ (>)}
\end{array}$$

c.

$$\begin{array}{ccccc}
\textit{banka} & \textit{-nın} & \textit{faiz} & \textit{oran} & \textit{-ı}\\
\text{bank} & \text{-GEN} & \text{interest} & \text{rate} & \text{-COMP.POSS}\\
\hline
N & N/(N\backslash N)\backslash N & N & N & N\backslash N\backslash N\backslash N\\
\hline
\multicolumn{2}{c}{N/(N\backslash N)\ (>)} & & \multicolumn{2}{c}{N\backslash N\backslash N\ (<)}\\
\hline
 & & \multicolumn{3}{c}{N\backslash N\ (<)}\\
\hline
\multicolumn{5}{c}{N: \mathsf{poss(comp\ rate\ interest)bank}\ (>)}\\
\multicolumn{5}{c}{\text{'interest rate of the bank'}}
\end{array}$$

d.

$$\begin{array}{ccccc}
\textit{banka} & \textit{-nın} & \textit{faiz} & \textit{oran} & \textit{-ları}\\
\text{bank} & \text{-GEN} & \text{interest} & \text{rate} & \text{-COMP.POSS.PLU}\\
\hline
N & N/(N\backslash N)\backslash N & N & N & N\backslash N\backslash N\backslash N\\
\hline
\multicolumn{2}{c}{N/(N\backslash N)\ (>)} & & \multicolumn{2}{c}{N\backslash N\backslash N\ (<)}\\
\hline
 & & \multicolumn{3}{c}{N\backslash N\ (<)}\\
\hline
\multicolumn{5}{c}{N: \mathsf{poss(plu(comp\ rate\ interest))bank}\ (>)}\\
\multicolumn{5}{c}{\text{'interest rates of the bank'}}
\end{array}$$

e. *kredi* *kart* *-ı* *faiz* *oran* *-ı*
credit card -COMP interest rate -COMP2

$$\begin{array}{llllll} N & N & N\backslash N\backslash N & N & N & N\backslash N\backslash N\backslash N \\ & \multicolumn{2}{c}{N\backslash N \;<} & & \multicolumn{2}{c}{N\backslash N\backslash N \;<} \\ \multicolumn{3}{c}{N \;<} & \multicolumn{3}{c}{N\backslash N \;<} \\ \multicolumn{6}{l}{N\!: \mathsf{comp}(\mathsf{comp\ rate\ interest})(\mathsf{comp\ card\ credit}) \;<} \end{array}$$

'credit card interest rate'

f.*kredi kart-ı yıllık faiz oran-ı*
annual
'credit card annual interest rate'

g.**kredi kart-ı faiz yıllık oran-ı*

7 Conclusion

Theoretical and computational commitment to word-based grammar—and regarding inflectional morphology as a word-internal process—puts artificial limits on specifying the syntactic and semantic domains of all meaning-bearing elements, and on the transparent projection of scope from the lexicon. Words as minimal units of the lexicon is too constraining for many languages. This traditional notion is also challenged in current linguistic theorizing, e.g., Jackendoff (1997), and Keenan and Stabler (1997). Marslen-Wilson (1999) argues on psycholinguistic grounds that the lexicon must be morphemic even for morphologically simpler languages such as English.

We have argued in this paper that the key to the integration of inflectional morphology and syntax is granting representational status to morphemes, which, in a computational system, requires certain precautions. What we propose is enriching the expressive power of the combinatory morphemic lexicon to factor in morphosyntactic types and attachment modalities. Coupled with flexible constituency in the grammar and directionality information coming from the lexicon, these extensions provide the grammar with the information it requires to compute the transparent semantics of morphosyntactic phenomena. This flexibility causes neither inefficiency in parsing, nor uncontrolled expressivity. The extensions do not affect the polynomial worst-case complexity results, and category unity is preserved by lattice consistency. The result is a morphemic grammar-lexicon with computationally desirable features such as modularity and transparency. The system is available at ftp://ftp.lcsl.metu.edu.tr/pub/tools/msccg.

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