Morphology in Constraint-based lexicalist approaches to grammar

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1 Introduction

1.1 Defining the terms

The term 'constraint-based lexicalism' (henceforth CBL) was coined in the mid 1990s to denote a set of linguistic theories sharing two main design properties:[1]

Strong lexicalism Morphology and syntax are separate dimensions of language, modelled by discrete components of a theory of grammar. The *word* is the interface between morphology and syntax: words are atoms of syntactic description, while morphology describes relations between words and/or relations between words and more abstract lexical entities (roots, stems, lexemes, affixes, morphophonological processes, etc.).

Constraint-based architecture A grammar is best stated as a set of constraints on possible linguistic objects. As in all formal theories of grammar, utterances and other linguistic objects are modelled by mathematical structures. What sets apart constraint-based theories is the use of a description logic (or set of such description logics) whose model theory makes explicit under what conditions a grammatical constraint is satisfied by a model.

Two immediate terminological clarifications are in order. First, one should not confuse *lexicalist theories of grammar* with *lexical theories of morphology*. While laying out a typology of morphological frameworks, Stump (2001) makes a distinction between *lexical* and *inferential* approaches. In a *lexical* approach, affixes are licensed by a lexicon of bound morphemes, whereas in an inferential approach they are licensed by syncategorematic rules. Stump's distinction says nothing about the relation between morphology and syntax—and indeed, non-lexicalist theories of grammar are usually lexical in their approach to morphology.

Second, in phonology, the term 'constraint-based' is used in quite a different fashion, and characterises the family of approaches, such as Optimality Theory (Prince and Smolensky, 1993) and Harmonic Grammar (Smolensky and Legendre, 2006), that rely on constraint competition rather than rule conspiracies to derive surface forms from underlying representations. The difference between this usage of 'constraint-based' and the one relevant here cannot be

[1] The term was also used in psycholinguistics to denote approaches to sentence processing (e.g. Trueswell and Tanenhaus 1994) that attribute central roles to lexical information and incremental processing in multiple dimensions.

overstated. First, within constraint-based lexicalist approaches, the logic of constraint interaction is based on conjunction rather than competition: any well-formed linguistic object has to satisfy simultaneously all constraints on objects of that type. By contrast, in Optimality Theory and related frameworks, output representations explicitly do not have to satisfy all constraints, and deciding which constraints have to be satisfied is the main analytic device. Second, constraint-based lexicalist approaches focus much attention on the precise formalisation of constraints and thus on the exact structural properties of models of linguistic reality. Most work in Optimality theory and related frameworks takes the precise formulation of constraints as unimportant, and focuses instead on the elaboration of the meta-theory of constraint interaction. While it is entirely possible to combine an optimality-theoretic approach to phonology with a lexicalist constraint-based approach to morphology (see e.g. Orgun 1996) — and there have been important proposals for using constraint competition to address morphological issues (e.g. Ryan 2010; Aronoff and Xu 2010; Round 2013) —, these two research traditions have developed largely independently of each other, and rely on very different intuitions on the adequate design of linguistic frameworks.

The two main contemporary theories that embrace both lexicalism and constraint-based architecture are *Lexical Functional Grammar* or LFG (Bresnan, 1982) and *Head-driven Phrase Structure Grammar* or HPSG (Pollard and Sag, 1987, 1994).[2] In this, they contrast strongly with mainstream generative grammar, including most versions of Government and Binding Theory, the Minimalist Program, and Distributed Morphology, which are neither lexicalist nor constraint-based.[3]

1.2 Morphological analysis in CBL frameworks

The hypothesis of strong lexicalism has put the focus of much work in CBL frameworks on the interface between morphology and syntax, with two main areas of research. On the one hand, research on the relation between featural representations in syntax and morphology has focused on case stacking (Nordlinger, 1998; Malouf, 2000; Sadler and Nordlinger, 2004), deponency (Vincent and Börjars, 1996; Sadler and Spencer, 2001), agreement features (Pollard and Sag, 1994; Kathol, 1999; Wechsler and Zlatić, 2003), and syncretism (Ingria, 1990; Dalrymple and Kaplan, 2000; Daniels, 2002; Levy and Pollard, 2002; Sag, 2003; Crysmann, 2009; Dalrymple et al., 2009). On the other hand, much attention has been devoted to linguistic phenomena presenting apparent challenges to strong lexicalism, including pronominal affixes or clitics (Miller, 1992; Miller and Sag, 1997; Crysmann, 2003a; Monachesi, 1999, 2000; Crysmann, 2003b; Bonami and Boyé, 2007; Penn, 1999; Samvelian and Tseng, 2010), portmanteau elements (Bender and Sag, 2000; Wescoat, 2002; Abeillé et al., 2003; Wescoat, 2007), particle verbs (Ackerman and Webelhuth, 1998; Kathol, 2000; Müller, 2003), and discontinuous affixation (Borsley, 1999; Kupść and Tseng, 2005; Crysmann, 1999, 2010a,b; Broadwell, 2008;

[2]LFG and HPSG also fall within the set of 'non-transformational' or 'surface-based' approaches (see Borsley and Börjars 2011 for a recent overview), along with, among others, *Tree Adjoining Grammar* and *Categorial Grammar*; however, the most popular formulations of these frameworks are not constraint-based. We will not devote much attention to the 'surface-based' nature of the frameworks under consideration, as this is of little consequence to the modelling of morphology.

[3]Of course the two properties are independent of one another. Most versions of Categorial Grammar are lexicalist but not constraint-based, relying on a proof-theoretic rather than model-theoretic approach to the modelling of syntactic relations. On the other hand, some model-theoretic approaches to syntax fall in the constraint-based camp without being lexicalist, e.g. the model-theoretic interpretation of Government and Binding Theory in Rogers (1998).

Fokkens et al., 2009). Periphrastic realisation of tense, aspect and mood has been a topic of much attention, with a clear contrast between reductionist approaches that treat the relation between auxiliary and main verb as purely syntactic (Hinrichs and Nakazawa, 1989; Bresnan, 2001; Abeillé and Godard, 2002; Müller, 2002; Frank and Zaenen, 2004) and the line of research initiated by Vincent and Börjars (1996) and Ackerman and Webelhuth (1998) which attempts to address paradigmatic aspects of periphrasis within a lexicalist framework (Sadler and Spencer, 2001; Ackerman et al., 2011; Bonami and Samvelian, 2009, 2015; Bonami, 2015).

Although a hypothesis about morphology is at the heart of the CBL view of grammar, it is striking that relatively little attention has been devoted within extant CBL theories to the modelling of morphology proper. Bresnan's (1982) celebrated lexical analysis of the English passive set the tone for much of the subsequent literature: while the paper provides strong arguments in favour of a morphological analysis of the English passive, and lays out consequences of that analysis for morphological theory, it contributes very little (pp. 17-19) in terms of concrete morphological analysis. The extensive literature on refinements of and alternatives to the Passive Lexical Rule over the next three decades (see among many others Pollard and Sag (1987), Kathol (1994), Ackerman and Webelhuth (1998), Bresnan (2001), Müller (2002), Sag et al. (2003)) makes little progress in the strictly morphological area. In this paper, we will focus on that sub-part of the CBL literature that deals with morphology itself.

The constraint-based lexicalist view of grammar entails few commitments as to the architecture of morphology, except for the commitment to lexicalism itself. In this context, it is telling that all of the three modes of morphological description envisioned by Hockett (1954) have been used by some authors. In LFG, an Item and Arrangement approach has been consistently consensual throughout the history of the framework, notably adopted in influential work such as Simpson (1991), Bresnan and Mchombo (1995), Nordlinger (1998) and Bresnan (2001). More recently, Sadler and Nordlinger (2004, 2006) explicitly interface a Paradigm Function Morphology approach (a variety of Word and Paradigm morphology) with an LFG grammar. Item and Arrangement approaches have been less prominent within HPSG: (Krieger et al., 1993) defend such an approach for derivation, explicitly building morphological tree structures analogous to syntactic phrase structure. However their approach was quickly criticised by Koenig (1994, 1999) and Riehemann (1993, 1998), who defend instead an Item and Process approach, insisting that words have recursive structure but affixes are not signs. This has become the standard approach for derivation, and is adopted, with minor variation, in publications such as Müller (2003), Bonami and Boyé (2006) or Sag (2012). For inflection, two tendencies may be observed. On the one hand, many publications assume that the same kind of Item and Process view relevant to derivation also applies—see among others Koenig (1999), Sag et al. (2003), Goodman and Bender (2010). On the other hand, following initial insights from (Pollard and Sag, 1987, 213), many studies advocate the adoption of a Word and Paradigm approach to inflection (Krieger et al., 1993; Erjavec, 1994; Bonami and Boyé, 2002; Crysmann, 2003b; Sag, 2012; Crysmann and Bonami, 2015).

1.3 Two contrasting architectures

LFG and HPSG belong to the class of 'feature-based' or 'unification-based' grammars, in which recursive feature structures and feature structure unification play a central role in modelling aspects of grammar. Despite this shared central property, however, these two frameworks are characterised by important architectural differences that do have a direct bearing on their approach to morphology.

The most distinguishing property of LFG is a multi-modular projection architecture where different modules of linguistic organisation, such as constituent structure, functional structure or semantics are not only distinct linguistic sub-theories, but these theories are essentially couched in different formalisms: context-free rewrite systems for constituency, a unification formalism for functional structure (including valency, case and agreement), and e.g. linear logic for semantic structure. With respect to morphology and the lexicon, we observe a similar picture, i.e. a preference for distinct module-specific formalisms: in addition to finite-state approaches to morphology (Koskenniemi, 1983b; Karttunen et al., 1992; Kaplan and Kay, 1994b), which are somewhat predominant, Sadler and Nordlinger (2004, 2006) have argued to embed Paradigm-Function Morphology as a morphological module in the LFG architecture. Generalisations in the lexicon are typically captured using lexical rules. Grammars implemented on the XLE grammar engineering platform (Maxwell III and Kaplan, 1993) additionally make use of macros in order to reuse information across classes of lexical entries. Thus, the choice of a particular formalism on the syntactic side does not have any direct influence on the choice of formalism or theory in morphology, in line with the overall spirit of LFG's projection architecture.

Turning to HPSG, an entirely different picture emerges: in contrast to LFG, no formal distinction is drawn between constituent structure and functional structure. Instead, all aspects of syntax are equally represented as (typed) feature structures. This fundamental property, namely the use of a single formalism to express different linguistic sub-theories, receives the status of an architectural leitmotif: although different semantic theories have been integrated into HPSG over the years (Situation Semantics, Barwise and Perry, 1983; Pollard and Sag, 1994; UDRT Reyle, 1993; Frank and Reyle, 1995), MRS (Copestake et al., 2005) or Montagovian Semantics (Richter and Sailer, 2003)), all of them are represented in terms of typed feature structures. Similar observations can be made for other grammatical modules, as diverse as information structure (Engdahl and Vallduví, 1994) or phonology (Bird and Klein, 1994). Given this overall approach of using a single formalism, a typed feature logic, to express different linguistic sub-theories, the way in which generalisation over lexical and morphological knowledge are captured is intimately linked to the way shared properties are abstracted out in other parts of the grammar, namely underspecification in feature structure inheritance hierarchies. Given the lexicalist nature of the framework, most of this work took its starting point in the lexicon (Flickinger, 1987), to be generalised to syntax (Sag, 1997), semantics (Ginzburg and Sag, 2000), and morphology (Krieger, 1994; Riehemann, 1998; Koenig, 1999; Crysmann and Bonami, 2015).

This contrast between the LFG and HPSG architectures clearly entails a different attitude towards morphology: HPSG, but not LFG, is committed to a tight integration of morphological with phonological, syntactic and semantic description. This perhaps explains the comparatively larger HPSG literature on morphology, which attempts to redeploy analytic techniques of underspecification, monotonic constraint interaction, and rich ontologies that have been instrumental to the success of the framework in other areas of grammar: LFG morphology tends to take the form of some preexisting approach to morphology interfaced with LFG. This also entails that there are fewer commonalities between the two frameworks in the domain of morphology than there are in the area of key syntactic phenomena such as valence alternations, control, or extraction. Rather than presenting two parallel lines of research, the present chapter will focus mainly on the HPSG literature on morphology. We refer the reader to Nordlinger and Sadler (forthcoming) for an overview of work on morphology in LFG.

2 Generalisation in the lexicon

2.1 Feature structures and underspecification

Across a number of grammatical frameworks, features are employed to represent properties of linguistic entities, permitting generalisation over individual properties, thereby responding to the granularity problem associated with the labels of pure context-free grammars. What sets LFG and HPSG apart from other mainstream Generative Grammar is their use of feature *structures*, in contradistinction to mere feature bundles, and the privileged status they assign to unification as the primary operation on these structures.

Feature structures, as used in HPSG, extend the basic formalism with the introduction of types: in typed feature structures, every value is a type, defined by a type signature, i.e. an ontology of admissible (linguistic) objects. The type signature defines not only which types exist, but also the subsumption relations between these types. For atomic values, the use of types allows natural classes of values to be represented in terms of sort hierarchies, as shown in Figure 1. These sortal hierarchies serve the further purpose of providing abstractions of subclasses suitable for underspecified descriptions. Since subsumption hierarchies are lattices (not just trees), so are type hierarchies: in essence, it becomes possible to define cross-classifying sortal hierarchies, where a particular type may be defined as the subtype of two (or more) supertypes, like e.g. *acc* in Figure 1.

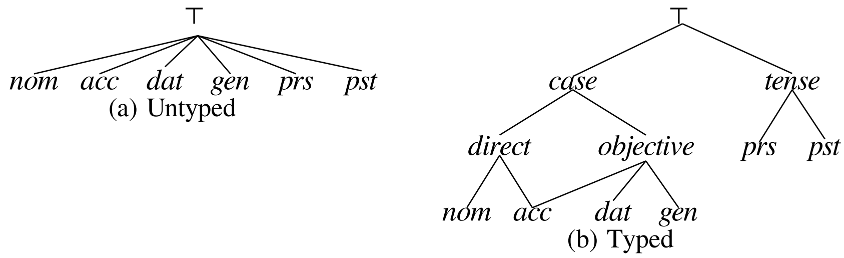

Figure 1: Hierarchies of atomic values in typed and untyped feature formalisms

HPSG typed feature structures extend the concept of a hierarchy of values from atomic to complex feature structures (see Kasper and Rounds (1986), Carpenter (1992), King (1989), and Richter (2000) on the formal foundations of typed feature structures). Thus, classes of linguistic objects with properties represented as features can also be organised into type hierarchies. The concept of typed complex feature structures is exploited in several ways. First, just like atomic sorts, complex types are organised into a hierarchy of types, representing an ontology of (linguistic) objects with properties. Still parallel to atomic sorts, this hierarchy of types defines which types are compatible with each other. Second, complex types declare which features they introduce, together with their values, such that only those features are licit which are appropriate for this type. The appropriateness condition thus makes it possible to infer not only the features for any given type, but also the maximal type for any feature. Furthermore, since every supertype in a type hierarchy represents a more general class than its subtypes, it must naturally subsume its subtypes, so the logic of typed feature structures is set up in such a way that any property asserted for a supertype must also hold for its subtypes. As a consequence, subtypes inherit all the properties that hold true of their supertype.

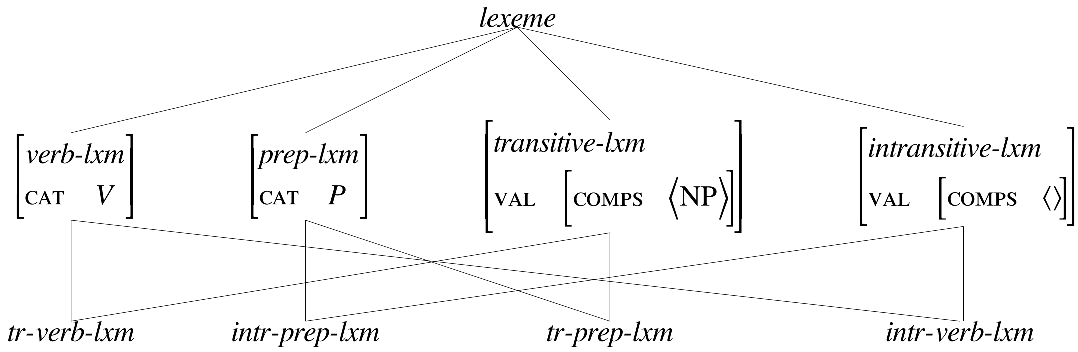

Figure 2: Cross-classification of category and valence properties

2.2 Inheritance hierarchies (vertical redundancy)

A basic assumption of constraint-based lexicalism is that rich lexical descriptions provide many of the constraints that a word puts on its syntactic context. This places a certain burden on the lexical component. Thus, a rich and articulate lexicon must be matched with powerful mechanisms to eliminate redundancy. Within HPSG, the concept of typed feature structures has been exploited from early on to represent lexical knowledge in terms of structured ontologies.

The expression of generalisations in the lexicon is intimately linked to the elimination of redundancy. The task of eliminating redundancy from lexical description can be broken down into two complementary sub-tasks (Pollard and Sag, 1987): so-called vertical redundancy, which relates to information shared by different (lexical) descriptions, and horizontal redundancy, which arises by virtue of systematic alternations observed for classes of descriptions.

Classificational devices such as type hierarchies are very good at eliminating vertical redundancy by means of class abstraction and inheritance: consider, e.g. the class of transitive verbs that make up the bulk of the lexical entries for verbs in the lexicon of many languages. Instead of stating over and over again the characteristic properties of transitives for each instance, these properties can be assigned to a superclass to be inherited by each of its subtypes. Using cross-classification, more and more abstract generalisations can be expressed, e.g. to facilitate generalisation of certain properties, like valency across major lexical classes, e.g. from verbs to prepositions (e.g. French *dans* 'in' vs. *dedans* 'inside'), as illustrated in Figure 2.[4]

While successful at the task of eliminating vertical redundancy, *static* type hierarchies by themselves prove a blunt tool when confronted with horizontal redundancy. To illustrate the problem, let us consider the case of passives: horizontal redundancy does not involve what information is shared, but rather what information changes in systematic ways. While static type hierarchies per se may serve to generalise separately the properties of active and passive verbs, when taken in isolation, they will fail to relate the class of active verbs to that of the corresponding passive ones.

[4]HPSG uses a rich and evolving feature geometry which can be baffling at times to the casual observer. For the purposes of this paper we have aimed at standardising the geometry, following mostly conventions from Sag et al. (2003), except when citing verbatim a published analysis. The following abbreviations are used in feature names: ACT: actor; AFF: affixes; AGR: agreement; CAT: syntactic category; COMPS: list of complements; CON: list of consonants; EVT: eventuality; IND: semantic index; M-DTRS: morphological daughters; MPH: set of morphs; MS: morphosyntactic property set; μ-FEAT: morphological features; MUD: morphology under discussion; NEG: negation; PC: position class index; PH: phonology; PREF: list of prefixes; RESTR: set of restrictions; RR: set of realisation rules; SEM: semantics; SKEL: phonological skeleton; SL: supralaryngeal; SOA: state of affairs; SUBJ: subject; TNS: tense; UND: undergoer; VAL: valence; VOW: list of vowels.

From the viewpoint of morphology, classificational systems may go some way at abstracting out shared properties of e.g. forms in a paradigm, both across all the cells of a single lexeme, and across analogous cells of different lexemes. Owing to the static nature of such ontologies, however, each and every cell still needs to be listed, together with all its subtype relations. In other words, what is clearly missing is a generative device that would turn these static ontologies into dynamic ones.

2.3 Lexical rules (horizontal redundancy)

Lexical rules have been the traditional device to attack the issue of horizontal redundancy in lexicalist theories, like LFG and HPSG. Despite the common name, the different concepts of lexical rules can be broken down along two binary oppositions: generative vs. redundancy rules and meta-level vs. description-level rules. Let us start with the rather well-known first distinction: while a redundancy rule interpretation may suffice to capture lexical relatedness, it does not reduce the size of the lexicon, at least when measured in terms of the number of lexical entries. Generative lexical rules, by contrast do permit reduction of the lexicon, but, conversely, will not be sufficient by themselves to account for cases of limited productivity. Within LFG and HPSG, lexical rules are most commonly understood as being of the generative, rather than the redundancy type.

The second distinction pertains to the status of such rules with respect to the general linguistic ontology: are they meta-statements that either generalise relationships between independently established lexical entries or serve to generate an extended lexicon from a basic one, or are they rather descriptions of possible lexical entities themselves? Traditionally, lexical rules in constraint-based lexicalism were of the former kind (Bresnan, 1982; Pollard and Sag, 1987, 1994).

$$\begin{bmatrix} \text{CAT} & V \\ \text{VAL} & \begin{bmatrix}\text{SUBJ} & \left\langle \mathrm{NP}_{\boxed{x}}\right\rangle \\ \text{COMPS} & \left\langle \mathrm{NP}_{\boxed{y}}\right\rangle\end{bmatrix} \\ \text{SEM} & \begin{bmatrix}\text{RESTR} & \left\{\begin{bmatrix}\text{ACT} & \boxed{x}\\ \text{UND} & \boxed{y}\end{bmatrix}\right\}\end{bmatrix}\end{bmatrix} \mapsto \begin{bmatrix}\text{VAL} & \begin{bmatrix}\text{SUBJ} & \left\langle \mathrm{NP}_{\boxed{y}}\right\rangle\\ \text{COMPS} & \left\langle \mathrm{PP}_{\boxed{x}}\right\rangle\end{bmatrix}\end{bmatrix}$$

Figure 3: A sample passive lexical rule

Within HPSG, consensus has clearly moved towards a description-level interpretation, regarding lexical rules as part of the lexicon itself (see e.g. Meurers 2002). Possibly the most straightforward description-level representation of lexical rules is that of a unary rule where the outer feature structure corresponds to the derived lexical entry, whereas the inner feature structure corresponding to the base is embedded under a feature which we will call here M-DTRS (morphological daughters). Meurers (2002) provides a method that automatically expands the traditional format shown in Figure 3, where unmentioned features are assumed to be carried over, into a description-level format similar to the one in Figure 4 where identities are made fully explicit.

When represented like this, lexical rules are themselves nothing but typed feature structures, and thus become amenable to the kind of class abstraction offered by typed feature formalisms.

$$\left[\begin{array}{ll} \textit{passive-lxm} & \\ \text{CAT} & \boxed{c} \\ \text{VAL} & \left[\begin{array}{ll} \text{SUBJ} & \left\langle \text{NP}_{\boxed{y}} \right\rangle \\ \text{COMPS} & \left\langle \text{PP}_{\boxed{x}} \right\rangle \end{array}\right] \\ \text{SEM} & \boxed{s} \\ \text{M-DTRS} & \left\langle \left[\begin{array}{ll} \text{CAT} & \boxed{c}\ V \\ \text{VAL} & \left[\begin{array}{ll} \text{SUBJ} & \left\langle \text{NP}_{\boxed{x}} \right\rangle \\ \text{COMPS} & \left\langle \text{NP}_{\boxed{y}} \right\rangle \end{array}\right] \\ \text{SEM} & \boxed{s} \left[\begin{array}{ll} \text{RESTR} & \left\{ \left[\begin{array}{ll} \text{ACT} & \boxed{x} \\ \text{UND} & \boxed{y} \end{array}\right] \right\} \end{array}\right] \end{array}\right] \right\rangle \end{array}\right]$$

Figure 4: Passive lexical rule as underspecified description of lexemes

We shall see some practical application to morphology in the following sections. This move parallels similar developments in HPSG syntax (Sag, 1997; Ginzburg and Sag, 2000), where phrase structure rules are equally organised into type hierarchies, ultimately providing a formal interpretation of constructions.

2.4 Online type construction

An entirely different tack on solving the issue of horizontal redundancy in static lexical type hierarchies has been pursued by Koenig (Koenig and Jurafsky, 1994; Koenig, 1999): instead of relying on an external device such as lexical rules, he identifies the static, closed world nature of lexical type hierarchies as the source of the problem and argues for a conception of lexical type hierarchies as a generative device.

In essence, Koenig achieves this by means of two fundamental assumptions: first, he suggests that types in lexical hierarchies do not directly license lexeme categories, but that lexeme categories are instead inferrable maximally specific (leaf) types. Second, he organises the type hierarchy into (conjunctive) dimensions. Well-formed lexeme categories are then obtained by inheritance from exactly one leaf type in every dimension, under unification. Leaf types within each dimension are disjunctive, and thus define the available lexical alternations. The system of conjunctive dimensions then ensures that every well-formed lexical category is defined with respect to these alternations. Let us illustrate the workings of online type construction using a simplified version of the active/passive alternation: as detailed in Figure 5,[5] crucial aspects of passive and active are abstracted out into separate underspecified lexeme types. Most crucially, lexical types capturing valence information (active vs. passive) are represented in a dimension distinct from the roots. In our example this is mostly the linking pattern for arguments. By way of systematic intersection of leaf types from each dimension of the minimal underspecified hierarchy (solid lines, white background), the full set of well-formed lexeme categories is derived (dashed lines, grey background). Thus elimination of horizontal redundancy is essen-

[5]This is a didactic version of Koenig's account of valence alternation, leaving out a lot of detail and linguistic generalisations.

tially reduced to dynamic cross-classification.

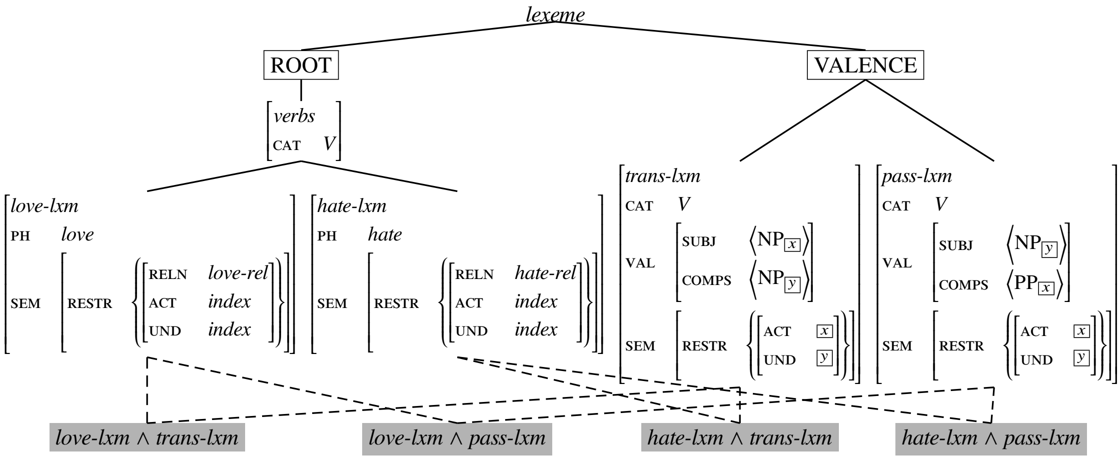

Figure 5: Online type construction

A particularly compelling property of online type construction is the integration of regular productive alternations (lexical or morphological) with exceptions, irregularities and sub-regularities. The key to this integration is pre-typing: while regular alternations will be characterised by online type constructions, nothing prevents us from pre-assigning exceptionally non-alternating items to a particular type in the relevant dimensions. For illustration, we shall have a look at exceptions to the active/passive alternation, in particular lexical *have* which happens not to passivize, despite having a suitable argument structure. Consider the partial lexical type hierarchy in Figure 6: contrary to lexemes such as *love*, *have* is not only a type in the ROOT dimension of the minimal hierarchy, but it is also pre-linked to a valence type, viz. *trans*. Since well-formed lexeme categories must be a subtype of exactly one type from each dimension, pre-linking trivially fulfils this requirement for the relevant dimensions. Moreover, since the leaf type for *have* already inherits from a type in the VALENCE dimension, alternation is effectively blocked, given that types within a dimension are disjoint. Verbs undergoing regular alternation, by contrast, are still captured, since they can freely intersect with the "open" subtypes for active and passive valencies.

The distinction between free online type construction (under unification) and pre-typing serves a very general role in Koenig's theory of the hierarchical lexicon. Koenig draws a systematic distinction between regular productive classes, which are intensionally described by reference to properties alone, from sub-regular and irregular classes, which are extensionally defined, i.e. by enumerating class members. Still, common properties of sub-regular patterns can be abstracted out vertically into the supertype. e.g. the sub-regular pattern of verb inflection witnessed by *ring* ~ *rang* will have all its members listed as subtypes, while capturing the systematicity of the unproductive pattern as a partial phonological description on the supertype. In a sense, supertypes in extensionally defined classes work like redundancy rules, wheres open types for intensionally defined classes work like generative rules.

Although they both address aspects of horizontal redundancy, online type construction and (description-level) lexical rules are not incompatible analytic devices: in fact Koenig (1999) explicitly argues for using a combination of both.[6] This is most useful in the modelling of lexeme formation, as we will see in the next section.

[6]The necessity of lexical rules is motivated by the recursive character of derivational morphology which is beyond the expressive power of type hierarchies, as pointed out by Krieger (1996) on the basis of German ex-

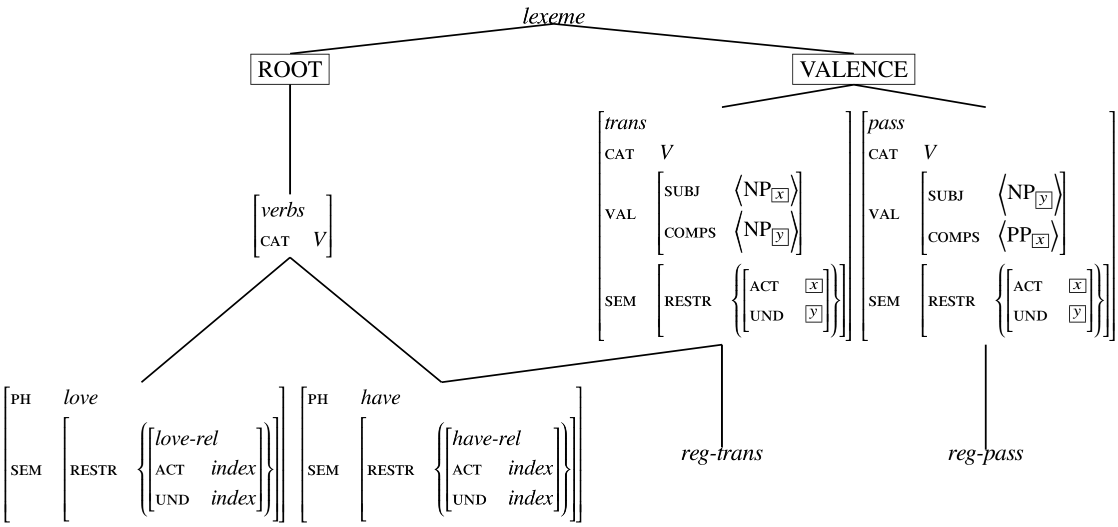

Figure 6: Exceptions via pre-typing

3 Morphology in CBL approaches

3.1 Lexeme formation

3.1.1 Lexeme formation processes in the hierarchical lexicon

The success of inheritance hierarchies in capturing generalisations and avoiding redundancy in the lexicon promptly led to the idea of using hierarchical classification to address productive lexeme formation. After an initial proposal by Krieger et al. (1993) to introduce derivational affixes as such in lexical hierarchies, Riehemann (1993, 1998) and Koenig (1994, 1999) independently proposed an architecture that came to be adopted in most subsequent work on lexeme formation in HPSG. We illustrate this by presenting a simplified analysis of *-able* adjectives in French, directly inspired by the analysis of German *-bar* adjectives in Riehemann (1998).[7]

As already stated in section 2.3, in recent versions of HPSG, lexical rules, and in particular lexeme formation rules, are seen as underspecified lexical entries with an open slot for a morphological base. This is best introduced through an example. Figure 7a is a possible lexical entry for the verb *laver* 'wash', specifying its phonology /lav/, its category as that of a verb, its valence as transitive (i.e. as taking two NP arguments) and its semantics as a ternary relation between an event and the two entities denoted by the two NPs.[8]
Figure 7b is a reasonable enough lexical entry for the adjective *lavable* 'washable' in the same format. The rough semantic characterisation is intended to capture the idea that *lavable* denotes the class of objects y such that for most events e and agents x, it is possible for x to wash y in e.

The lexical rule relating *laver* to *lavable* can then be recast as an underspecified lexical

amples like *vor-vor-vor-gestern* 'before-before-before-yesterday (=4 days back)'. For non-recursive inflectional morphology, by contrast, the motivation for lexical rules is greatly reduced.

[7]See Hathout et al. (2003) for a thorough desctiption of the system of French *-able* adjectives. Although we sketch here only a small subpart of the system, the data uncovered by Hathout *et al.* as a whole lends itself straightforwardly to the type of analysis illustrated here.

[8]For simplicity and readability we adopt semantic representations in the style of Sag et al. (2003), and leave all quantificational aspects of semantic representations implicit. Nothing hinges on this presentational convenience.

$$\begin{bmatrix} \textit{lexeme} & \\ \text{PH} & /\text{lav}/ \\ \text{CAT} & V \\ \text{VAL} & \begin{bmatrix}\text{SUBJ} & \left\langle \text{NP}_{\boxed{x}}\right\rangle \\ \text{COMPS} & \left\langle \text{NP}_{\boxed{y}}\right\rangle\end{bmatrix} \\ \text{SEM} & \begin{bmatrix} \text{IND} & \boxed{e} \\ \text{RESTR} & \left\{\left(\begin{bmatrix}\textit{wash-rel} & \\ \text{EVT} & \boxed{e} \\ \text{ACT} & \boxed{x} \\ \text{UND} & \boxed{y}\end{bmatrix}\right)\right\}\end{bmatrix}\end{bmatrix}$$

(a) *laver* ‘wash’

$$\begin{bmatrix} \textit{lexeme} & \\ \text{PH} & /\text{lavabl}/ \\ \text{CAT} & A \\ \text{SEM} & \begin{bmatrix} \text{IND} & \boxed{x} \\ \text{RESTR} & \left\{\left(\begin{bmatrix}\textit{possible-rel} & \\ \text{SOA} & \begin{bmatrix}\textit{wash-rel} & \\ \text{EVT} & \boxed{e} \\ \text{ACT} & \boxed{x} \\ \text{UND} & \boxed{y}\end{bmatrix}\end{bmatrix}\right)\right\}\end{bmatrix}\end{bmatrix}$$

(b) *lavable* ‘washable’

Figure 7: Sample entries of a French verb and its corresponding *-able* adjective

entry for an adjective, capturing what is common to regular *-able* adjectives, and relating their properties to that of their base through the dedicated attribute M-DTRS whose value is a partial description of the base.[9] This is sketched in Figure 8. This schematic lexical entry is satisfied whenever one can find a transitive verb with phonology $\boxed{1}$ expressing a ternary relation *R*, and specifies that to this verb corresponds an adjective with phonology /$\boxed{1}$+abl/ and appropriate semantics. The important point to note is that Figure 8 has exactly the same formal status as the descriptions in Figure 7: it is just a partial description of a set of lexemes, which happens to be strongly underspecified. Note that under this conception, lexeme formation rules are essentially indistinguishable from the constructional schemata later to be popularised by Booij (2010).

The striking advantage of modelling lexeme formation rules as underspecified lexical entries is that it allows one to capture simultaneously the productive nature of lexeme formation, the existence of lexicalised exceptions to the productive rule, and the commonalities between strict adherents to the productive rule and other cases. This can be done by carefully integrating productive rules in a lexical sub-hierarchy of *-able* adjectives. Consider the partial hierarchy in Figure 9, which is intended as a sub-part of a full hierarchical representation of the French lexicon.

This hierarchy groups together all adjectives that are perceived to belong to the class of *-able* adjectives, even where they exhibit an idiosyncratic syntactic (*adorable* ‘adorable’, meaning ‘that should be adored’ rather than ‘that could be adored’) or semantic (*fiable* ‘reliable’ based on a verb with an indirect rather than direct object) relation to their base. Thus, as indicated in Figure 9, the only thing that is common to members of the *-able* type are the category and phonology alternations. Appropriate generalisations on syntax and semantics can be captured by the subtypes *reg-syn-able* and *reg-sem-able*, while still allowing for the possibility of lexically listed exceptions to these generalisations for cases like *adorable* and *fiable*.

Fully regular *able* adjectives belong to the type *reg-able*, and hence inherit both from regular syntax and semantics; in effect, *reg-able* is associated by inheritance with the constraint in Figure 8.

[9]Technically, M-DTRS is list-valued, to accommodate for the possibility of multiple bases in the case of compounding.

$$\begin{bmatrix} \textit{lexeme} & \\ \text{PH} & \boxed{1}+\text{/abl/} \\ \text{CAT} & A \\ \text{SEM} & \begin{bmatrix} \text{IND} & \boxed{x} \\ \text{RESTR} & \left\{\begin{bmatrix}\textit{possible-rel} & \\ \text{SOA} & \boxed{2}\end{bmatrix}\right\}\end{bmatrix} \\ \text{M-DTRS} & \left\langle \begin{bmatrix} \textit{lexeme} & \\ \text{PH} & \boxed{1} \\ \text{CAT} & V \\ \text{VAL} & \begin{bmatrix}\text{SUBJ} & \left\langle \text{NP}_{\boxed{x}}\right\rangle \\ \text{COMPS} & \left\langle \text{NP}_{\boxed{y}}\right\rangle\end{bmatrix} \\ \text{SEM} & \begin{bmatrix}\text{RESTR} & \left\{\boxed{2}\begin{bmatrix}\textit{agentive-rel} & \\ \text{ACT} & \boxed{x}\end{bmatrix}\right\}\end{bmatrix}\end{bmatrix}\right\rangle \end{bmatrix}$$

Figure 8: Lexical entry for *lavable* ‘washable’

An appealing feature of the present approach is that it is agnostic as to the listing of redundant lexical information. Although not strictly necessary to attain descriptive adequacy, it is entirely possible to list explicitly particular instantiations of a lexeme formation rule, as this is done for *readable* in Figure 9. This fits well with the observation that speakers do memorise frequent, yet predictable words (see e.g. Bertram et al. 2000), but that what is redundantly lexicalised may vary from speaker to speaker.

Another appealing property of the approach is that it easily scales up to more complex systems of morphological relationships. Consider the existence of a nonproductive subclass of *-ible* adjectives sharing the same syntactic and semantic conditions as *-able* adjectives. Some adjectives (e.g. *divisible* ‘divisible’ based on *diviser* ‘divide’, *exigible* ‘due’ based on *exiger* ‘require’) are formed just like *-able* adjectives, the only difference being vowel quality. Some others (e.g. *prédictible* ‘predictable’, *audible* ‘audible’ are based on a learned root but are still arguably related to some contemporary French verb (*prédire* ‘predict’, *ouir* ‘hear’). Still others may fail to entertain a morphological relationship to any verb at all (*plausible* ‘plausible’, *tangible* ‘tangible’). This situation can be captured using an enriched hierarchy and multiple inheritance, as indicated in Figure 10.
In this particular hierarchy, the type *-ble* just constrains its instances to be adjectives with phonology ending in /bl/. Types in the VOW dimension introduce different choices for the preceding vowel. Types in the other three dimensions specify the relationship of the adjective to its base, respectively in terms of phonology, syntax, and semantics. Each of these three dimensions contains a *regular* subtype stating the expected, normal situation; exceptions are pre-linked to the top of the dimension. It should be transparent how the constraints from the previous hierarchy in Figure 9 need to be redistributed on types *-ble*, *-able*, *reg-phon*, *reg-syn*, and *reg-sem*. The difference in productivity between *-ible* and *-able* is captured by the fact that *-able*, but not *-ible*, has a subtype leaving open the identity of the base lexeme. Among members of the *-ible* family, three situations are found. *Divisible* is maximally regular and derives all its

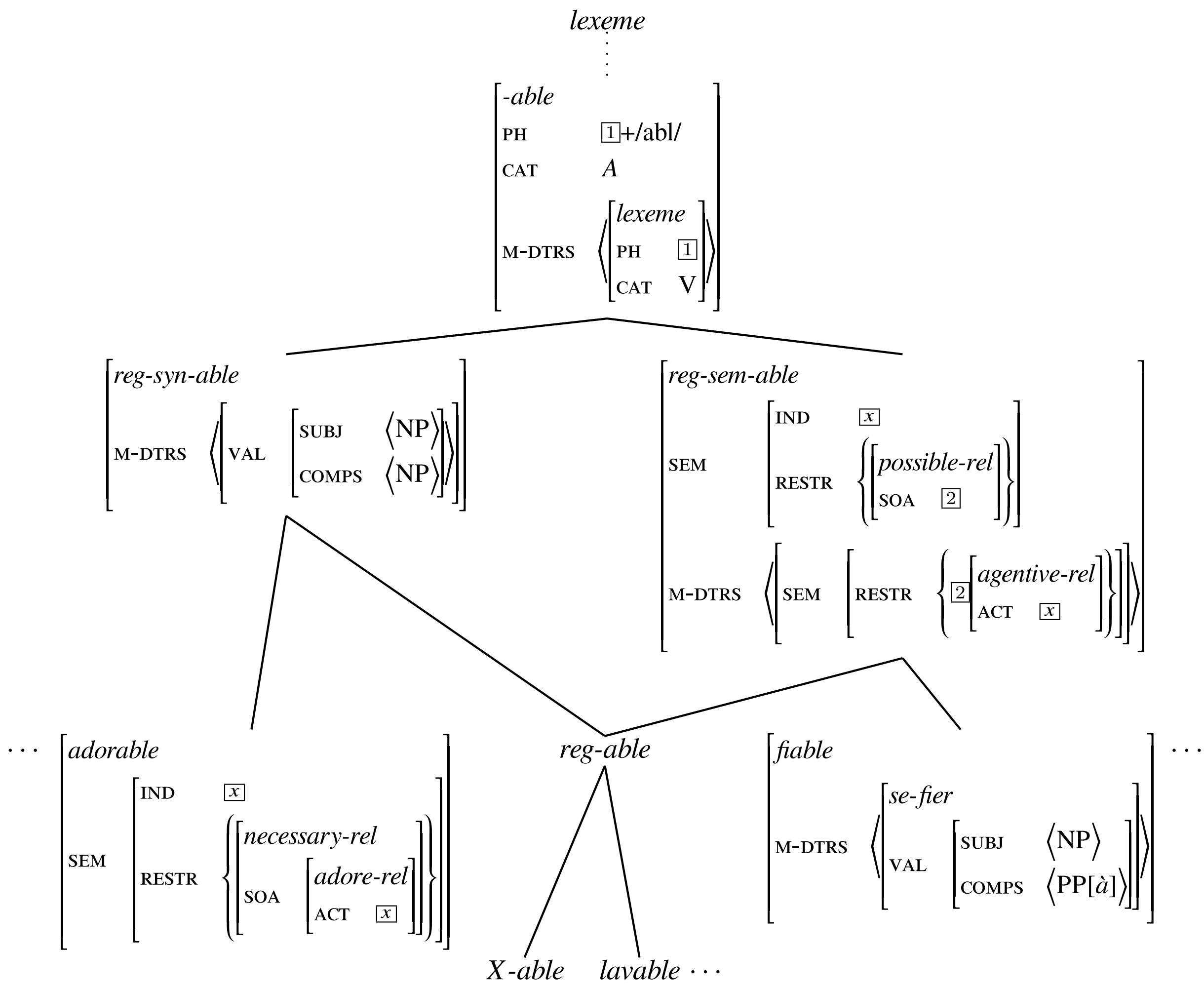

Figure 9: A partial hierarchy of French *-able* adjectives

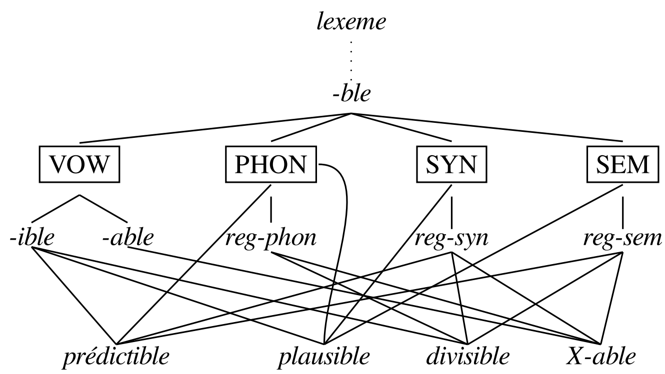

Figure 10: A joint partial hierarchy of *-able* and *-ible* adjectives

properties from its base *diviser*. *Prédictible* is irregular in not deriving its phonology from that of its base *eat*, but is still fully regular in syntax and semantics. *Plausible* is maximally irregular, and does not share any property with other members of the family besides ending in /-ibl/.

3.1.2 Multidimensional classification of lexeme formation rules

In the preceding section we focused on addressing the diversity of instantiations of a single lexeme formation process. Recent work on word formation has highlighted the importance of rivalry between processes: more often than not, a language offers more than one means to fill the onomasiological need for a new lexeme L' expressing meaning M' on the basis of an existing lexeme L expressing meaning M. A relevant example is that of English denominal verbs: as argued at length by Plag (1999), processes such as *-ize* suffixation, *-ify* suffixation, *be-* prefixation, and conversion, give rise to overlapping types of meanings, so that in some instances any of the processes could have been used to fill the same lexical need. When combined with the well-known observation that individual processes themselves are polysemous (for a recent appraisal see Luschützky and Rainer 2013), this leads to the view that lexeme formation involves a many-to-many relation between formal processes and semantic relations to be expressed.

Table 1 illustrates this situation with examples from French deverbal nouns. Empty cells in the table correspond to situations where there is no productive formation, although a few stray examples may exist.[10] As the examples in the table make clear, the many-to-many relation does not entail that there is no conventionalised association between form and meaning that needs to be encoded in an appropriate grammar: some processes definitely exclude some meanings (e.g. conversion never constructs agent nouns), and processes may be more or less selective as to the kinds of semantic relation they encode (compare *-eur* and compounding). Thus what is needed is some economical way to encode the similarities and differences between formation processes.

	-oir	*-age*	*-eur*	compounding	conversion
Patient	*tiroir* 'drawer'	—	—	—	*affiche* 'poster'
Instrument	*hachoir* 'chopper'	maquillage 'makeup'	*tracteur* 'tractor'	*essuie-glace* 'wiper'	*réveil* 'alarm clock'
Agent	—	—	*nageur* 'swimmer'	*garde-côte* 'coastguard'	—
Location	*lavoir* 'washing place'	*garage* 'garage'	—	*appui-tête* 'headrest'	*décharge* 'garbage dump'
Event	—	*guidage* 'guidance'	—	*rase-mottes* 'hedgehopping'	*dépose* 'removal'

Table 1: Examples of combinations of formal processes and meanings in French deverbal nouns.

Inheritance hierarchies of lexeme formation rules again provide an adequate solution to the problem, as shown notably in Desmets and Villoing (2009) and Tribout (2010, 2012). For clarity we focus on the first three rows (Patient, Instrument and Agent) and three columns (*-oir*, *-age* and *-eur*) of Table 1. Figure 11 presents an appropriate inheritance hierarchy.

[10]Here we rely heavily on extant detailed empirical studies: Villoing (2002) for VN compounds, Namer and Villoing (2008) for *-oir* nouns, Tribout (2010) for conversion, Huygue and Tribout (2015) for *-eur* nouns.

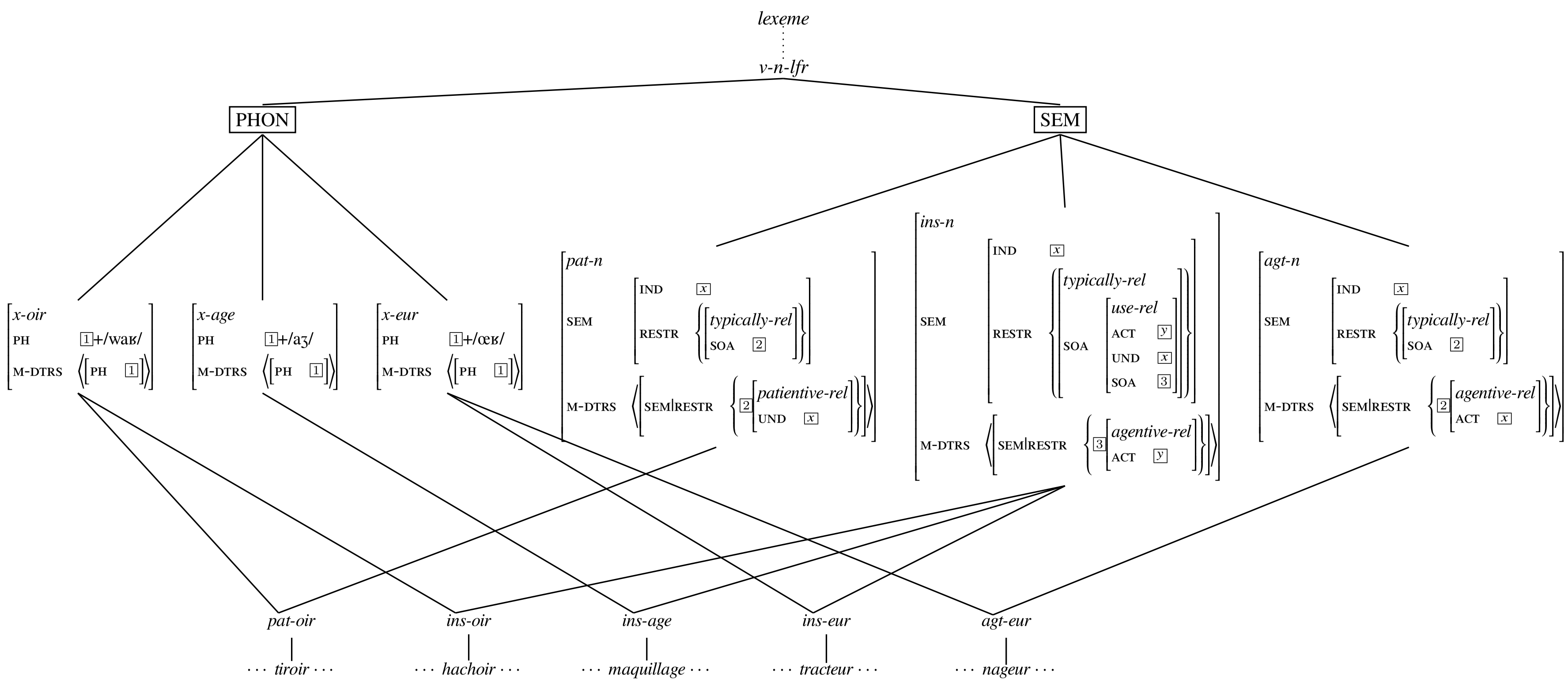

Figure 11: Multiple inheritance hierarchy of lexeme formation rules accounting for aspects of the French data set in Table 1

Constraints on types in the PH dimension that are parallel to those posited earlier for *-able* adjectives. The constraints on types in the SEM dimension in Figure 11 are worth elaborating a bit. The type *agt-n* indicates that the base must denote a relation involving an agent, or *agentive-rel*, and constructs a noun denoting a typical agent of that relation. The type *pat-n* is entirely parallel, but this time involving patients rather than agents. The type *ins-n* is a bit more elaborate: the base has to be an agentive relation (instruments presuppose the existence of an agent using them to complete some action), and the derived noun denotes a class of objects used by an agent to bring about the action corresponding to that agentive relation—technically, the semantics of the noun embeds the relation *use-rel* between an agent $\boxed{y}$, a patient $\boxed{x}$ and a state of affairs $\boxed{3}$ such that $\boxed{y}$ uses $\boxed{x}$ to bring about $\boxed{3}$.

There are a number of distinct advantages to using this format to describe a system of lexeme formation processes. First, the multiple inheritance hierarchy is flexible enough to capture both situations where a process is associated with a natural class of semantic relations and those where it is not. For instance, *-eur* suffixation selects those semantic relation that rely on an agentive base: this can readily be stated as a further constraint on type *x-eur*; on the other hand, other processes exemplified in Table 1 involve irreducible polysemy, which calls for an explicit listing of the possibilities. Second, the hierarchy can be readily interpreted as guiding both coining and parsing of new words. When coining a new word, a speaker knows what content she seeks to convey, and hence which subtype of SEM to use: the problem is to decide on an adequate PHON type to combine it with. When parsing an unknown word, the speaker can readily infer the PHON type, and needs to determine an appropriate SEM type to get to the intended meaning. Third, the analytic apparatus presented above in paragraph 3.1.1 can be redeployed to account for the relationship between online creation of lexemes (through underspecified M-DTRS values) and lexicalised items. Fourth and finally, a multiple inheritance hierarchy of complex lexemes is a natural starting point to address the variable productivity of lexeme formation processes while taking into account the overall productivity of the formal operation and semantic relation they combine.

3.2 Inflectional morphology

As we have observed above, the constraint-based perspective on syntax and semantics does not strictly entail a particular view on the kind of morphology to be adopted: thus, all three approaches identified by Hockett (IA, IP, WP) have at some point been adopted by different practitioners of HPSG and LFG. Apart from this purely historical fact, it is equally true that there is a somewhat stronger affinity in constraint-based lexicalist theories with item-and-process and word-and-paradigm approaches than with item-and-arrangement.

The kind of phenomena subsumed under the label of grammatical function change (involving inter alia the active-passive and causative-inchoative alternations) have always enjoyed a pivotal role in lexicalist approaches to syntax and semantics. Owing to the fact that these kinds of alternations are standardly captured by means of lexical rules, it is quite natural to encode any morphophonological effect as part of such rule application. Thus, the wide-spread adoption of an IP approach can be considered as epiphenomenal to the way systematic lexical alternations have been captured within these frameworks.

A more recent typology of inflectional theories has been proposed by Stump (2001), who classifies approaches along two binary distinctions, i.e. lexical vs. inferential and incremental vs. realisational approaches. While classical morpheme-based theories (IA) are both lexical and incremental — morphological function is considered a lexical property of individual morphemes and complex functions are derived by incrementally combining morphemes into complex forms —, Word-and-Paradigm approaches, by contrast, associate morphological function with the word as a whole (inferential) and allow for many-to-many correspondences in the mapping of form and function (realisational). The constraint-based perspective on grammar shares a high degree of similarity to the inferential view on inflection: owing to monotonicity, a lexemic description is typically understood to be compatible with each and every cell of the paradigm, and inflection rules, however implemented, merely serve to monotonically narrow down which set of paradigm cells a word may realise (Krieger and Nerbonne, 1993).

Among inferential-realisational (WP) approaches to inflection, Paradigm Function Morphology (Stump, 2001) has enjoyed a privileged status in both LFG and HPSG, for several reasons: first and foremost, the level of formal explicitness attained by PFM clearly surpasses that of other WP approaches, such as Anderson's A-morphous Morphology, which makes PFM an adequate companion for these thoroughly formalised grammatical frameworks.[11] Second, compared to AM, PFM minimises the amount of extrinsic ordering, being more compatible in spirit with the constraint-based enterprise. Third, the formal nature of PFM, as functions from morphosyntactic properties to word forms make for a straightforward integration into both LFG and HPSG, despite the underlying formal differences between PFM and feature logic.

In HPSG, several attempts have been made to integrate PFM-inspired inflectional morphology more seamlessly with the logic of typed feature structures (Erjavec, 1994; Miller and Sag, 1997; Bonami, 2011; Sag, 2012; Ackerman and Bonami, in press), thereby providing a clean interface to syntax and semantics. As discussed in Erjavec (1994), once a notion of the Elsewhere Condition is in place, PFM can even be translated quite faithfully into a constraint-based theory such as HPSG. However, none of these approaches takes full advantage of the design properties of monotonic constraint-based approaches. In practice, the expression of inflection is usually relegated to a function that essentially plugs the input and output of a PFM grammar into HPSG.

3.2.1 Inferential realisation morphology in typed featured structure

More recently (Crysmann and Bonami, 2012; Bonami and Crysmann, 2013; Crysmann and Bonami, 2015), the present authors have developed an inferential-realisational model of inflectional morphology that seamlessly integrates with the declarative, model-theoretic framework of HPSG. The model systematically exploits feature structure underspecification in monotonic inheritance hierarchies to express generalisations across rules, replacing the procedural residue of AM and PFM with a purely information-based notion of wellformedness and competition.

We first present the basic workings of Information-based Morphology (henceforth IbM) and then argue that it is both more restrictive and less prone to arbitrary decisions than previous inferential-realisational approaches.

Figure 12 illustrates the IbM feature geometry by showing the word-level description of the English adjective *smaller*. The task of morphology is conceived as to relate a set of morphosyntactic properties (MS) to a phonological representation (PH). This relation is mediated by

[11] Contemporary lexical-realisational approaches such as Distributed Morphology have never been considered as suitable models of inflectional morphology for either LFG or HPSG, due to several reasons: first, incompatible assumptions about Lexical Integrity, second, the idiosyncratic and MP-specific assumptions about syntactic input structures, third, the reliance on destructive operations on features (checking, impoverishment), and fourth, the absence of sizeable and sufficiently formalised grammar fragments.

two intermediate representations: a set of realisation rules (RR) and a set of morphs indexed for position (MPH). Each rule states that a given subset of morphosyntactic properties, referred to by MUD, is realised by some set of morphs in a context that may be restricted through reference to other features in the set MS. In the case at hand, exactly two rules regulate the introduction of exactly two morphs: a rule of *stem introduction* ($\boxed{6}$) realises lexical identity ($\boxed{1}$) by introducing the lexically specified stem ($\boxed{5}$) as the phonology of the morph in position 1 ($\boxed{3}$), and a simple rule of exponence ($\boxed{7}$) realises comparative degree ($\boxed{2}$) as an appropriate morph in position 2 ($\boxed{4}$).

$$\begin{bmatrix} \text{PH} & /\text{smɔːlə}/ \\ \text{MPH} & \left\{ \boxed{3}\begin{bmatrix}\text{PH} & /\text{smɔːl}/ \\ \text{PC} & \mathit{1}\end{bmatrix}, \boxed{4}\begin{bmatrix}\text{PH} & /\text{ə}/\\ \text{PC} & \mathit{2}\end{bmatrix}\right\} \\ \text{MS} & \boxed{0}\left\{\boxed{1}\begin{bmatrix}\mathit{small} & \\ \text{STEM} & /\text{smɔːl}/\end{bmatrix}, \boxed{2}\begin{bmatrix}\text{DEGREE} & \mathit{comp}\end{bmatrix}\right\} \\ \text{RR} & \left\{\boxed{6}\begin{bmatrix}\text{MPH} & \boxed{3}\begin{bmatrix}\text{PH} & \boxed{5}\end{bmatrix} \\ \text{MUD} & \boxed{1}\begin{bmatrix}\mathit{lid} & \\ \text{STEM} & \boxed{5}\end{bmatrix} \\ \text{MS} & \boxed{0}\end{bmatrix}, \boxed{7}\begin{bmatrix}\text{MPH} & \boxed{4}\\ \text{MUD} & \boxed{2} \\ \text{MS} & \boxed{0}\end{bmatrix}\right\}\end{bmatrix}$$

Figure 12: IbM representation for the English adjective *smaller*

In accordance with lexicalism, the features MPH and RR are internal to the workings of morphology, and thus not visible to syntax: from the point of view of syntactic rules, words are pairings of phonology and (syntactic and semantic) content with no internal structure.[12] Thus the use of explicit segmented morphs as part of the morphological analysis of a word has no dire consequence on the morphology-syntax interface.

One of the most basic tasks of any inferential-realisational approach to morphology is the definition of morphological well-formedness: while in incremental approaches, completeness (properties must have a realisation) and coherence (realisations must be licensed by properties) are warranted by the very workings of the approach, inferential approaches actually need to assert these properties in one way or another: otherwise even bare stems will be erroneously regarded as a full realisation of every cell of the paradigm. While AM and PFM address this issue by postulating a sequence of rule blocks that needs to be processed in order to arrive at a well-formed word, IbM insists that wellformedness should rather be guaranteed in terms of the information to be expressed: every piece of the morphosyntactic property set must be licensed by exactly one realisation rule. To this end, realisation rules distinguish between properties they express (MUD) and properties they are merely conditioned on (MS). As stated by the principle in Figure 13, the MUD values of all the rules invoked must yield exactly the morphosyntactic property set MS of the word.

Realisation rules themselves are organised in a type hierarchy, permitting vertical abstraction of properties shared across different rules, both on the side of morphosyntactic features

[12]One way of implementing this locality condition is to model signs and the constructions licensing them as separate entities (Sag, 2012). Under such an approach MPH and RR would be modelled as part of an inflectional lexical construction.

$$
\textit{word} \rightarrow \begin{bmatrix} \text{MPH} & \boxed{e_1} \cup \cdots \cup \boxed{e_n} \\ \text{MS} & \boxed{0} \left(\boxed{m_1} \uplus \cdots \uplus \boxed{m_n}\right) \\ \text{RR} & \left\{ \begin{bmatrix} \text{MPH} & \boxed{e_1} \\ \text{MUD} & \boxed{m_1} \\ \text{MS} & \boxed{0} \end{bmatrix}, \ldots, \begin{bmatrix} \text{MPH} & \boxed{e_n} \\ \text{MUD} & \boxed{m_n} \\ \text{MS} & \boxed{0} \end{bmatrix} \right\} \end{bmatrix}
$$

Figure 13: Morphological well-formedness: completeness and coherence

being expressed, and on the side of exponence. Consider the partial hierarchy of realisation rules for Swahili tense markers in Figure 14. Leaf types for progressive and past tense pair the morphosyntactic property that is expressed by the rule with an exponent (in MPH), describing its shape (PH). Position class information shared by all tense markers is represented as a property of the immediate supertype, which the subtypes will inherit. The type at the top of the hierarchy captures the highly general property holding for all realisation rules, namely that morphosyntactic properties that are expressed must by necessity be part of the morphosyntactic property set MS. The rule type at the top left corresponds to what Stump (2001) has dubbed the Identity Function Default, i.e. a rule of zero exponence. In IbM, there is exactly one instance of this rule type, which is constrained to realise exactly one element of the morphosyntactic property set, not contributing any morphs. Note that IbM incorporates a version of Pāṇini's principle. Thus, leaf types in the hierarchy need not be manually declared as mutually exclusive: in cases of competition for realisation of some MUD, only the rule putting the most specific constraint on MS can apply.[13]

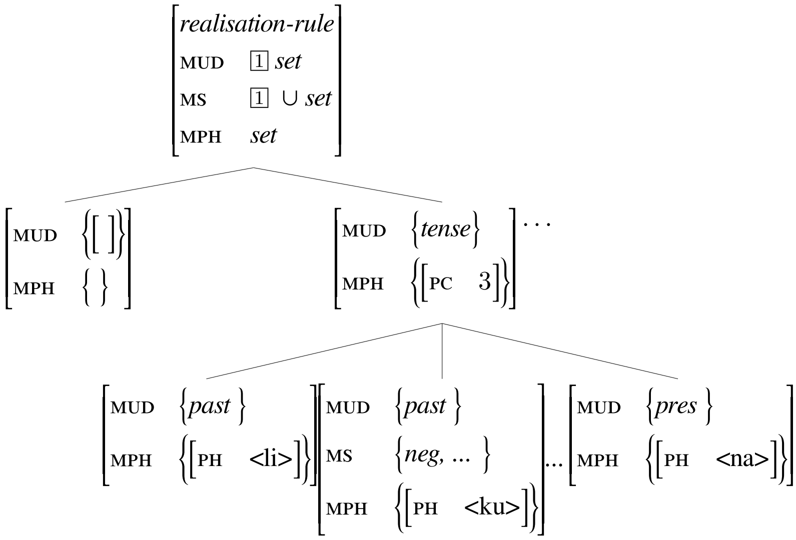

Figure 14: Hierarchy of tense realisation rules in Swahili

Building on Koenig's Online Type Construction (see section 2.4), systematic alternations in position can be captured by means of dynamic cross-classification of types from different dimensions. As Stump (1993) notes, exponents of subject and object agreement in Swahili are

[13]Technically, this is done by enriching the description of leaf types with the negation of the descriptions of all less specific competitors. This compilation step allows for incorporating the effects of Pāṇini's principle while staying true to the monotonous character of HPSG. See Crysmann and Bonami (2015) for the details of this view of Pāṇinian competition, which relies heavily on earlier work by Andrews (1990), Erjavec (1994), Koenig (1999).

identical in shape in almost all cells of the paradigm, despite the fact that the markers of these distinct functions are realised in different positions of the inflectional template (see Table 2 on page 24). By organising the type hierarchy of realisation rules into two dimensions, as shown in Figure 15, placement depending on grammatical function can be distributed over the rule types describing exponence, ultimately yielding the fully expanded leaf types at the bottom of the hierarchy.

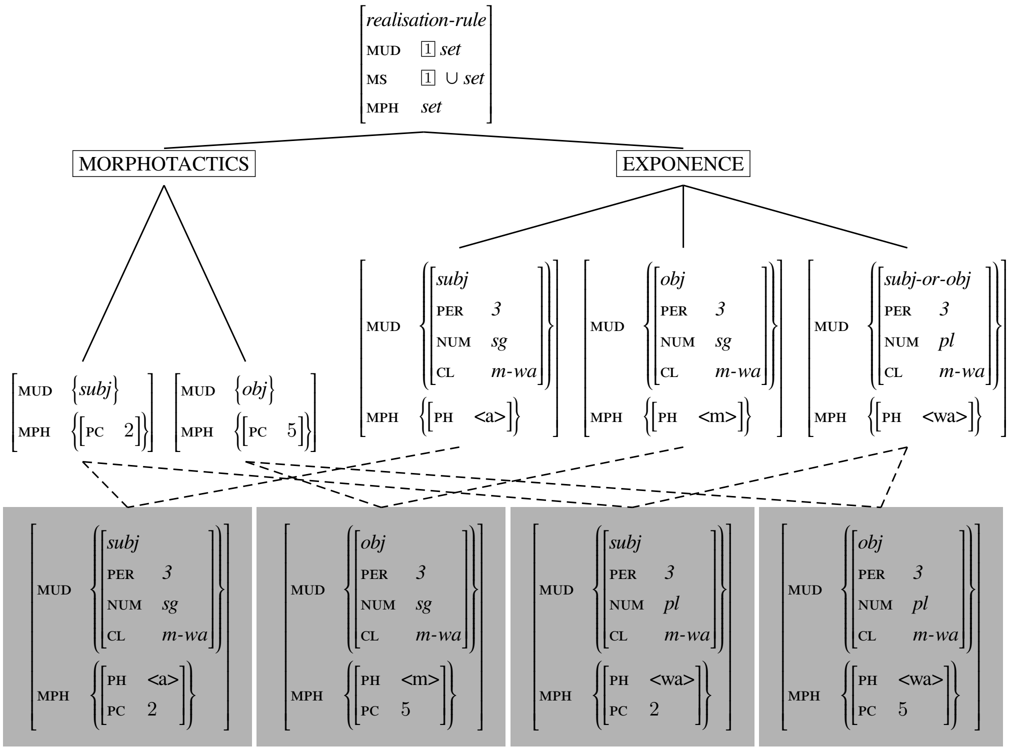

Figure 15: Rule type hierarchy for Swahili parallel position classes

Realisation rules, as shown thus far, pair a morph with some morphosyntactic property it expresses. While such $1 : 1$ correspondences arguably constitute the canonical case, IbM realisation rules equally permit the statement of $m : n$ correspondences. As a first deviation from the canon, we have already discussed zero exponence, i.e. the (default) rule that may express some morphosyntactic property without introducing any exponent. Other deviations correspond to cumulative and extended exponence: the first case is illustrated by the rule for the Swahili negative first singular subject portmanteau *si* in Figure 16. The second case, i.e. where a single morphosyntactic property corresponds to multiple, possibly discontinuous morphs is exemplified by the Chintang negative circumfix.[14] The possibility of capturing extended exponence head on by way of simultaneous introduction of exponents is opened up by the design decision for a morphous approach, where positional information is associated with the morphs themselves. In contrast to PFM or AM, IbM can capture $m : n$ relations not only on the level of the word, but also on the level of individual rules, pairing multiple properties with multiple, possibly discontinuous exponents.

As should be clear from the previous discussion, Information-based Morphology shares crucial properties with other members of the family of extended word-and-paradigm approaches,

[14]See Crysmann (in press) for simultaneous introduction of multiple morphs in Nyanja pre-prefixation.

$$\left[\begin{array}{ll} \text{MUD} & \left\{ \begin{bmatrix} \textit{subj} & \\ \text{PER} & \textit{1} \\ \text{NUM} & \textit{sg} \end{bmatrix}, \textit{neg} \right\} \\ \text{MPH} & \left\{ \begin{bmatrix} \text{PH} & \text{<si>} \\ \text{PC} & 1 \vee 2 \end{bmatrix} \right\} \end{array}\right]$$

(a) Cumulation

$$\left[\begin{array}{ll} \text{MUD} & \left\{ \textit{neg} \right\} \\ \text{MPH} & \left\{ \begin{bmatrix} \text{PH} & \text{<ma>} \\ \text{PC} & 1 \vee 2 \vee 3 \end{bmatrix}, \begin{bmatrix} \text{PH} & \text{<yokt>} \\ \text{PC} & 5 \end{bmatrix} \right\} \end{array}\right]$$

(b) Circumfixation

Figure 16: $m : n$ correspondences between MUD and MPH

like PFM or AM: it is realisational rather than lexical in the sense that expression of morphological properties is not associated with morphemes, but rather effected by rule application, which may introduce zero, one, or more than one exponent; and it is inferential, rather than incremental, as the morpho-syntactic property set is associated with the word, rather than built up step by step by the application of rules.

We close this discussion of IbM by highlighting some of its conceptual advantages over alternative inferential-realisational frameworks.

Restrictiveness An obvious property that contrasts inflectional morphology with both derivational morphology and syntax is its finiteness: for a given set of lexemes there is a finite bound both on the number of distinct words instantiating these lexemes and on the length of these words. IbM captures this boundedness straightforwardly by not using any recursive operation in the derivation of word forms: words are sequences of morphs licensed by realisation rules, and the number of realisation rules in a word is bounded by the number of morphosyntactic properties to be expressed. This is in stark contrast with the situation in PFM, where conspirations of rules of referral can in principle be stated so as to give rise to infinite derivations. Even disregarding rules of referral, the morphological structures generated by IbM evidently belong to a smaller class than those generated by PFM, as the derivation has the structure of a string (i.e. a structure with a single ordering relation) rather than a tree (i.e. a structure with two ordering relations).

Avoidance of arbitrary decision One of the main motivations for the design of IbM was dissatisfaction with the notion of a rule block. In both AM and PFM, rule blocks assume the double role of (i) allowing for extended exponence by exempting exponents in different blocks from competing for realisation, and (ii) regulating the order of exponents. While using a single device to address these two issues seems appealing at first, there are distinct drawbacks to both aspects of the solution. First, the block architecture prevents one from addressing the phenomenon of "discontinuous bleeding" (Noyer, 1992) as Pāṇinian competition between elements in different syntagmatic classes. Second, the relative order of prefixal and suffixal rule blocks is in many cases an arbitrary decision (Crysmann and Bonami, 2012):[15] in a system with m prefixal positions and n suffixal positions, there are $2^{\min(m,n)}$ distinct but empirically equivalent ways of stating the system.

IbM avoids both issues. Pāṇinian competition is global: decision on the applicability of a realisation rule is decided purely on the basis of the informativeness of the description;

[15] In rare instances, phonological or morphological properties can be used to argue that some block must feed another block. In practice that is the exception rather than the rule.

hence rules targetting different positions do compete if their MUD features stand in a subset relation. Second, the position class index of a morph is strictly constrained by its linear position relative to other morphs, hence there is no arbitrary decision to be taken in that respect.

One place where IbM could be seen as prone to making arbitrary decisions is in the treatment of extended exponence. There are two ways of dealing with extended exponence in IbM. Where the two exponents realise exactly the same set of features, they are introduced simultaneously by a single rule, as in Figure 16b. In situations of overlapping exponence, IbM relies on a distinction between realisation of a feature and allomorphic conditioning, formally cashed out as the distinction between a feature mentioned as part of MUD or MS. Although it sometimes occurs that more than one partition of the expressed features is conceivable, Crysmann (in press) shows that arbitrariness can be avoided by turning Carstairs's (1987) notion of Pure Sensitivity into a formal principle of the theory.

Morphousness IbM departs from both AM and PFM in recognising segmented morphs.[16] This move is a crucial precondition to an adequate treatment of extended exponence that does not rely on rule blocks. It also allows for a statement of inflectional morphology that is clearly neutral as to generation vs. parsing. This makes it obvious how IbM could be interfaced with a realistic model of human morphosyntactic processing, as partial representations of the content of words can be constructed incrementally on the basis substrings identified as known morphs. IbM is thus readily compatible with the Competence Hypothesis (Kaplan and Bresnan, 1982, 173): morphological analyses take a form that can be interpreted in terms of performance.

It is worth noticing that while IbM is decidedly morphous, Anderson's (1992) main argument against morphous approaches is entirely moot in the present context. Anderson's point is that morphological operations are never sensitive to the derivation history of their input; hence an appropriately restrictive theory should not make a record of that derivation history. This argument however relies on the presupposition that words are derived by a sequence of recursive operations. This is not the case in IbM: realisation rules have no input, they are just pairings of content with sets of morphs; and there is no order to the application of realisation rules, which are just all satisfied simultaneously. In the present context then, the situations that amorphousness was designed to avoid are already excluded by the very definition of realisation rules. Hence there is no benefit in terms of restrictiveness to being amorphous, and morphousness plays a crucial role in making a more restrictive theory of morphological derivation possible.

3.2.2 Morphotactics

The treatment of morph order, in particular the treatment of complex templatic systems, has attracted quite a good deal of attention in HPSG morphology. Alongside more traditional IA or IP approaches which treat the issue of order as essentially an epiphenomenon of combinatory

[16] These segmented morphs are however not morphemes in any classical sense: words are *not* represented as sequences of minimal pairings of form and content, since the distribution of morphs is regulated by realisation rules, and realisation rules may introduce zero, one, two or more morphs. Words are rather represented as sequences of recurrent phonological strings, which stand in a nontrivial relation to content. See also Spencer (2003, 2013) for convergent proposals for the use of morph lists in inferential-realisational morphology.

constraints, a number of dedicated approaches have been developed that specifically seek to capture linearisation properties of position class systems in a more direct fashion.

Construction-based morphotactics (Koenig, 1999) Probably the first such proposal has been developed by Koenig (1999), defending a construction-based view of Swahili position class morphology. Koenig takes as a starting point the claim advanced by Zwicky (1991) and Stump (1993) that the kind of dependencies observable between exponents in non-adjacent surface slots, as witnessed with Swahili negation, support a realisational, but not a constituent-structure based view of morphology.

(1) a. wa- li- som-a
SBJ.3PL.M/WA PST read
'they did read'

b. ha- wa- ku- som-a
NEG SBJ.3PL.M/WA NEG.PST read
'they did not read'

(2) a. wa- ta- som-a
SBJ.3PL.M/WA FUT read
'they will read

b. ha- wa- ta- som-a
NEG SBJ.3PL.M/WA FUT read
'they will not read

c. ni- ta- som-a
SBJ.1.SG FUT read
'I will read'

d. si- ta- som-a
NEG.SBJ.1.SG FUT read
'I will read'

In (1), the choice of past marker in slot 3 depends on the presence of negation in slot 1. Similarly, the negative first singular portmanteau in (2) constitutes a local dependency. Koenig shows that the difficulties faced by constituent structure approaches are not inherent to constituency per se, and shows how his constructional take on constituency in morphology allows the insertion of parts of the template at once. Using cross-classification of construction types, however, this somewhat holistic perspective can be decomposed into constituting parts.

$$\begin{bmatrix} \text{PH} & \begin{bmatrix} \text{AFF} & \begin{bmatrix} \text{PREF} & \langle \ldots, \ldots, \text{ku} \rangle \end{bmatrix} \end{bmatrix} \\ \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \mu\text{-FEAT} & \begin{bmatrix} \text{NEG} & + \\ \text{TNS} & \textit{pst} \end{bmatrix} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

(a) *neg-past*

$$\begin{bmatrix} \text{PH} & \begin{bmatrix} \text{AFF} & \begin{bmatrix} \text{PREF} & \langle \text{si}, < >, \ldots \rangle \end{bmatrix} \end{bmatrix} \\ \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \mu\text{-FEAT} & \begin{bmatrix} \text{NEG} & + \\ \text{SUBJ-AGR} & \begin{bmatrix} \text{PER} & \textit{1} \\ \text{NUM} & \textit{sg} \end{bmatrix} \end{bmatrix} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

(b) *1-sg-neg*

Figure 17: Sample types for Swahili

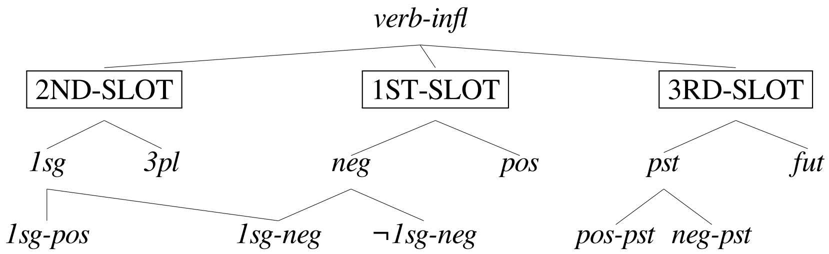

Figure 18: Koenig's constructional approach to Swahili position classes

Consider the definition of *neg-past* in Figure 17a: the crucial point is that for position class systems, Koenig assumes that not just one affix is introduced, but that the types of the hierarchy in Figure18 jointly constrain the three members of the PREF list: while *neg-pst* constrains the third element, intersection of this type with compatible types from the other two dimensions will select the appropriate affixes for the other slots. Koenig's approach to the Swahili template in terms of cross-classification of partial description is quite representative of construction-based HPSG in general, combining holistic description with decomposition into partial constraints.

PER	GEN	SUBJECT		OBJECT		RELATIVE	
		SG	PL	SG	PL	SG	PL
1		ni	tu	ni	tu		
2		u	m	ku	wa		
3	M/WA	a	wa	m	wa	ye	o
	M/MI	u	i	u	i	o	yo
	KI/VI	ki	vi	ki	vi	cho	vyo
	JI/MA	li	ya	li	ya	lo	yo
	N/N	i	zi	i	zi	yo	zo
	U	u	—	u	—	o	—
	U/N	u	zi	u	zi	o	zo
	KU	ku	—	ku	—	ko	—

Table 2: Swahili person markers

There are, however, some problems associated with a direct encoding of template slots: in order to ensure that some slots must remain empty for some cells in the paradigm, Koenig is forced to stipulate zero morphs, as in Figure 17b, in contrast to realisational morphology which would rather demand the absence of morphs in such cases. Another problem directly related to the direct association of forms with template positions concerns the scalability of Koenig's proposal: as illustrated in Table 2, exponents for subject and object agreement in Swahili draw on an almost identical inventory of shapes. Positionally and functionally, subject and object markers are clearly distinct. Any direct encoding of a fixed template will make it impossible to capture their commonalities, since it precludes the systematic separation of the dimensions of position and shape. Swahili relative makers constitute a similar challenge: the markers listed in Table 2 undergo a positional alternation between slots 4 and 7, essentially conditioned on tense properties (slot 3). This very conditioning on slot 3 will entail that the relative markers should be inserted on a prefix list together with tense, but assignment of these shapes to a fixed list position will preclude generalisation of form across the different slots they may surface in.

Morphotactics by precedence constraints (Crysmann, 2003b) A different approach to position class morphology has been developed by Crysmann (2003b) in the context of pronominal affix clusters in European Portuguese and their placement interaction with TAM markers. Building on ideas initially discussed in an appendix to Stump (1993), he proposes a realisational approach to inflection where rules of exponence recursively licence the presence of morphs on an essentially flat list representation. In order to describe the placement possibilities of these morphs by means of linear precedence statements, the morphs themselves are organised into type hierarchies of shapes, such that ordering constraints can target entire distributional classes, rather than having to be stated over and over again for each pair of morphs. While successful at achieving this task, Stump (p.c.) notes a certain degree of duplication between hierarchies of realisation rules and these distributional hierarchies over exponents. A central aspect of using LP constraints pertains to the possibility of partial order specifications, which opens up the possibility that syntax and morphology may jointly determine order of phonological contributions. Apart from European Portuguese clitics, the approach has been applied to Polish mobile affixes (Crysmann, 2010a), circumfixation to separable preverbs in Fox (Crysmann, 1999), endo-cliticisation in Udi (Crysmann, 2003b) and Sorani Kurdish (Bonami and Samvelian, 2008).

Morphotactics in Information-based Morphology Complex morphotactic systems have been the core phenomenon behind the development of IbM (see section 3.2.1). Crysmann and Bonami (2012) reinvestigate the classical challenges of Swahili and Fula variable morphotactics and argue for a systematic division between exponence and position. Their initial approach, which stayed quite close to PFM in recognising cascaded rule blocks, improved on Stump (1993) by using underspecified, cross-classifying description to capture generalisation on order independently from those on shape, providing an account for ambifixal, reversible, portmanteau and parallel position classes using a single descriptive device, i.e. partial rule description organised in a multidimensional Koenig-style type hierarchy. The crucial change compared to PFM is to dissociate order from rule blocks and associate it directly with the exponents, thereby bringing position class indices into the scope of realisation rule descriptions. Thus, in contrast to PFM, which employs several distinct devices to cope with non-canonical morphotactics, Crysmann and Bonami (2012) consistently exploit underspecification to generalise over exponence and morphotactics.

Rule blocks have been dropped entirely in subsequent work (Bonami and Crysmann, 2013; Crysmann and Bonami, 2015), yielding the purely information-based model presented in section 3.2.1. To illustrate the workings of their approach for the description of variable morphotactics, consider the data in (3–4) and the corresponding analysis in Figure 19:

(3) a. a-soma-**ye**
M/WA.S-read-M/WA.REL
'(person) who reads'

b. a-ki-soma-**cho**
M/WA.S-KI/VI.O-read-KI/VI.REL
'(book) which he reads'

(4) a. a-na-**ye**-soma
M/WA.S-PRES-M/WA.REL-read
'(person) who is reading'

b. a-na-**cho**-ki-soma
M/WA.S-PRES-KI/VI.REL-KI/VI.REL-read
'(book) which he is reading'

As illustrated in (3), Swahili relative markers, which agree with the relativised subject or object are realised in post-stem position 7 with affirmative definite tensed verbs, whereas they appear in slot 4 in all other tense/polarity combinations, as shown in (4). Despite the placement alternation, the shape of the relative marker remains constant across the paradigm of forms given in Table 2.

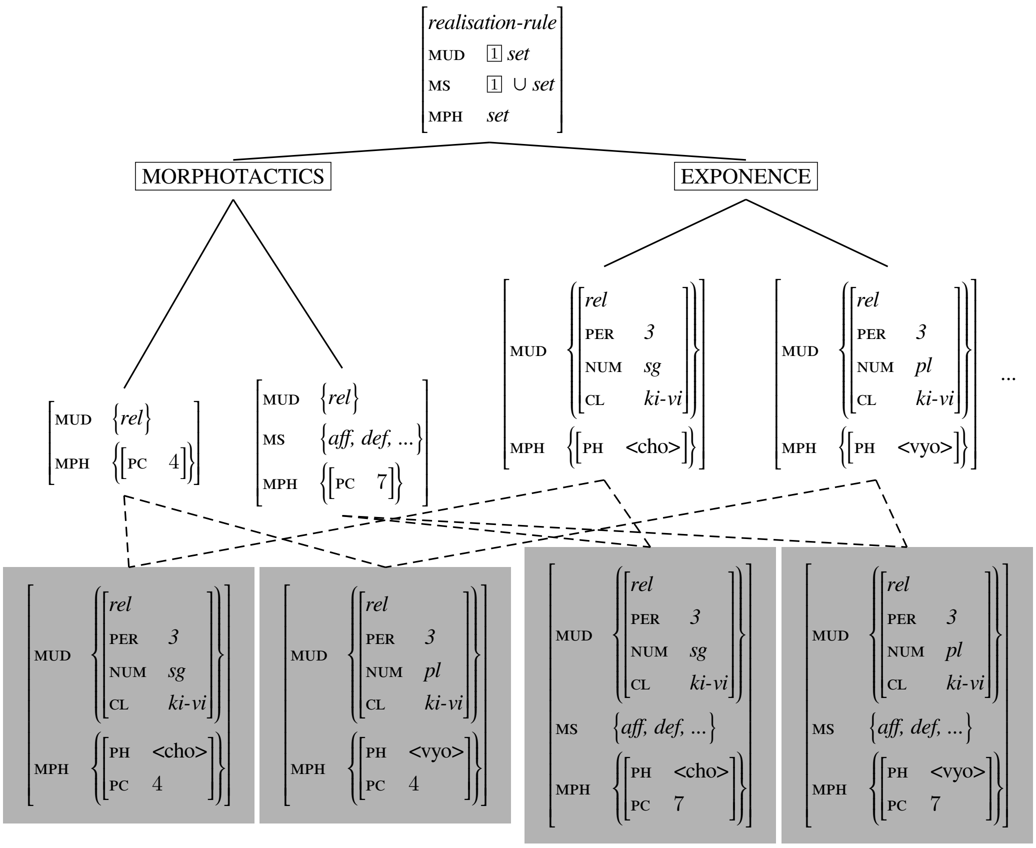

Figure 19: Partial hierarchy of Swahili relative markers (Crysmann and Bonami, 2015)

Using Koenig's Online Type Construction, rule descriptions are abstracted out into partial constraints on shape and constraints on order from which the actual rule instances (in grey) can be inferred by means of systematic intersection of the constraints from one dimension with those of the other. Note that on the level of formal devices being invoked, this analysis is strictly parallel to that of subject and object markers in Figure 15, the only difference between these phenomena being that morphotactic variation correlates with a conditioning property (MS) here, whereas it correlates with an expressed property (MUD) in the case of parallel position classes.

Backed by an extensive canonical typology of variable morphotactics, Crysmann and Bonami (2015) apply their basic underspecification approach to a wider array of phenomena, including free and partially constrained order in Chintang (Bickel et al., 2007) or Mari (Luutonen, 1997), or placement relative to a pivot, as witnessed by second position affixes in Sorani Kurdish or mobile stems in Italian (Bonami and Crysmann, 2013).

3.2.3 Morphophonology

Owing to the fact that both LFG and HPSG are not only theoretical, but also computational linguistic frameworks, their treatment of phonology, and therefore morphophonology, has been greatly influenced by research into Finite State methods and the usefulness of these approaches as a computational model of SPE-style cascaded rule systems (Kaplan and Kay, 1994b; Koskenniemi, 1983b). As for LFG, the projection architecture and the assumption of module-specific formalisms provide for a very easy and straightforward integration of these approaches. Within HPSG, Krieger et al. (1993) have shown how finite state transducers can be represented in terms of typed feature structures, permitting the mapping of lexical phonological representations onto surface phonology. They argue in particular that each step in a morphological derivation should be associated with such a mapping, thereby following quite closely the model of Lexical Phonology (Kiparsky, 1982, 1985).

The early 1990s, however, have seen the emergence of Declarative Phonology (Scobbie, 1991, 1993) or One-level Phonology (Bird and Klein, 1994; Bird and Ellison, 1992), which marks a more radical departure from the heritage of SPE-style Generative Phonology or Two-Level Morphology (Koskenniemi, 1983b). In a true constraint-based spirit, well-formed surface strings are described directly by a set of inviolable universal and language specific constraints that narrow down the properties of the phonological representation. Thus, instead of turning a sequence of underlying, typically fully specified phonological representations into a surface phonological representation, generalisations are rather captured by means of combining partial descriptions of the surface representation. As stated by Bird (1995), One-level Phonology thus revives ideas from Natural Generative Morphology, including the notion of archiphonemes, i.e. underspecified alternant sets that model surface alternation of phonological segments. Choice between alternants in the set is then effected by general surface constraints on the phonological representation.

The concrete phonological analyses developed within this framework incorporate a number of contemporary approaches to phonological description: in particular, feature structure representations are chosen to model feature trees as proposed in Feature Geometry (Clements, 1985). As illustrated in Figure 20, phonological representations are lists of feature structure descriptions of phonological events, and general phonological constraints are expressed as (possibly recursive) constraints on these lists: in the case of homorganic nasal assimilation, the constraint invalidates any sequence where a nasal precedes a [−continuous] segment, yet place of articulation is not shared. Note that "feature spreading" is captured by way of token-identity, i.e. structure sharing of feature values.

$$\neg\left\langle \ldots \begin{bmatrix} \text{SL} & \begin{bmatrix} \text{MANNER} & \begin{bmatrix} \text{NASAL} & + \end{bmatrix} \\ \text{PLACE} & \boxed{1} \end{bmatrix} \end{bmatrix}, \begin{bmatrix} \text{SL} & \begin{bmatrix} \text{MANNER} & \begin{bmatrix} \text{CONT} & - \end{bmatrix} \\ \text{PLACE} & \neg\,\boxed{1} \end{bmatrix} \end{bmatrix} \ldots \right\rangle$$

Figure 20: Homorganic nasal assimilation (Bird and Klein, 1994, 462)

Furthermore, Bird and Klein (1994) and Bird (1995) incorporate ideas from Autosegmental Phonology (Goldsmith, 1976; Leben, 1973), and suggest to represent linking of e.g. consonantal and vocalic tiers in Sierra Miwok by means of structure sharing. Owing to its commitment to monotonicity, viz. the information-preserving character of unification, concrete descriptive devices such as delinking are rejected.

For illustration, consider Bird and Klein's (1994) analysis of Sierra Miwok templatic morphology: essentially, they propose that an autosegmental representation as in Figure 21 can be represented by the feature structure in Figure 22.

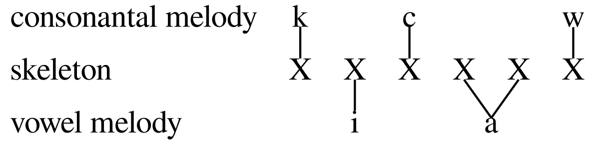

Figure 21: Autosegmental representation of Sierra Miwok *kicaaw* (Bird and Klein, 1994, 471)

$$\begin{bmatrix} \text{CON} & \left\langle \boxed{1}\,\text{k}, \boxed{3}\,\text{c}, \boxed{5}\text{w} \right\rangle \\ \text{VOW} & \left\langle \boxed{2}\,\text{i}, \boxed{4}\,\text{a} \right\rangle \\ \text{SKEL} & \left\langle \boxed{1},\boxed{2},\boxed{3},\boxed{4},\boxed{4},\boxed{5} \right\rangle \end{bmatrix}$$

Figure 22: AVM encoding of autosegmental representation (Bird and Klein, 1994, 471)

They propose further to abstract out general class-specific properties into distinct types, as illustrated in Figure 23.

$$\textit{bleed-lex} \rightarrow \begin{bmatrix} \text{PHON} & \begin{bmatrix} \textit{template-I} & \\ \text{CON} & \left\langle \text{k, c, w} \right\rangle \\ \text{VOW} & \left\langle \text{i, a} \right\rangle \end{bmatrix} \end{bmatrix} \quad \textit{quit-lex} \rightarrow \begin{bmatrix} \text{PH} & \begin{bmatrix} \textit{template-II} & \\ \text{CON} & \left\langle \text{c, l, k} \right\rangle \\ \text{VOW} & \left\langle \text{e, u} \right\rangle \end{bmatrix} \end{bmatrix}$$

(a) Lexical entries

$$\textit{template-I} \rightarrow \begin{bmatrix} \text{CON} & \left\langle \boxed{1}, \boxed{3}, \boxed{5} \right\rangle \\ \text{VOW} & \left\langle \boxed{2}, \boxed{4} \right\rangle \\ \text{SKEL} & \left\langle \boxed{1},\boxed{2},\boxed{3},\boxed{4},\boxed{4},\boxed{5} \right\rangle \end{bmatrix} \quad \textit{template-II} \rightarrow \begin{bmatrix} \text{CON} & \left\langle \boxed{1}, \boxed{3}, \boxed{4} \right\rangle \\ \text{VOW} & \left\langle \boxed{2}, \boxed{5} \right\rangle \\ \text{SKEL} & \left\langle \boxed{1},\boxed{2},\boxed{3},\boxed{4},\boxed{5} \right\rangle \end{bmatrix}$$

(b) Templates types

Figure 23: Separation of morphological templates from lexical entries

One of the criticisms that has been raised against the One-level approach pertains to the complete absence of feature changing operations, suggesting the generative power of the one-level approach to be insufficient to address the empirical patterns. Orgun (1996) cites data from Bengali that crucially illustrate this point:

(5) ʃat b^{h}ali — ʃadb^{h}ali
seven brothers

(6) mɔd k^{h}ɑoɑ — mɔtk^{h}ɑoɑ
alcohol drinking

Since the final consonants of *ʃat* and *mɔd* surface as such prevocalically, yet undergo voicing assimilation pre-consonantally, Orgun (1996) contends that the one-level model will be unable to distinguish these segments, assigning identical lexical representations, i.e. [PHON ⟨...,{d,t}⟩] to both cases.

An ingenious way to address this issue in a systematic way has been developed by Walther (1999): he suggests augmenting the representation of segments (which are actually constraints on the segments' properties) with constraints on the properties of their left and right neighbours.

$$\left[\begin{array}{ll}\textsc{ph} & \left\langle \ldots, \left[\begin{array}{ll}\textsc{self} & \left[\begin{array}{ll}\multicolumn{2}{l}{\textit{con}}\\ \textsc{laryngeal} & \left[\textsc{voiced}\ +\right]\end{array}\right]\\ \textsc{right} & \textit{vow}\end{array}\right] \vee \left[\begin{array}{ll}\textsc{self} & \left[\textsc{laryngeal}\ \left[\textsc{voiced}\ \boxed{1}\right]\right]\\ \textsc{right} & \left[\begin{array}{ll}\multicolumn{2}{l}{\textit{con}}\\ \textsc{laryngeal} & \left[\textsc{voiced}\ \boxed{1}\right]\end{array}\right]\end{array}\right]\right\rangle\end{array}\right]$$

Figure 24: Bengali voicing assimilation using contextualised phonologies

Similar to his approach towards contextualised alternation, Walther (1999) proposes to represent syllable structure in terms of role information on the segments themselves. In essence, this move lays the foundations towards a "lexicalised" representation of the entire prosodic hierarchy, as developed in Crysmann (2003b, ch. 6). A particularly nice property of representing prosodic structure in terms of prosodic roles is that it obviates the need for a context-free prosodic constituent structure, a formal representation that is largely under-motivated in phonological theory, owing to the absence of center self-embedding and more generally the absence of truly recursive structures, which clearly distinguishes the prosodic hierarchy from e.g. syntactic trees. Moreover, properties of prosodic organisation can be directly read off the primary, linear structure of phonological representation, including prosodic adjunction.

Owing to its strict adherence to monotonicity, which is anathema to both classical rule-based approaches and the kind of ordered violable constraints employed in OT, the one-level approach has only enjoyed a limited impact on theory construction in Generative Phonology. An alternative route has been pursued by Orgun (1996) who proposes to interface constraint-based lexicalist syntax and morphology with an OT phonology component. While successfully maintaining compatibility with phonologists outside constraint-based lexicalist grammar, Orgun's approach, however, was never really successful within HPSG, since the massive default character of OT clearly runs counter to the standard assumption about monotonicity and compositionality that are assumed in other parts of the grammar. For most approaches to morphophonology, however, the potential limitations of the One Level approach are less acute, since the morphological composition structure inherently provides for two phonological representation, i.e. one on the morphological daughter and another on the mother.

3.3 The interface between lexeme formation and inflection

Implicit in the discussion so far is the common assumption within HPSG of a split view of morphology (Perlmutter, 1988; Anderson, 1992): lexeme formation, including derivation and compounding, is regarded as distinct from inflection. In HPSG this is naturally accommodated by assuming a split in the hierarchy of signs, as indicated in Figure 25. Lexical signs come in two varieties, words and lexemes. The type *lex-sign* delimits the domain of morphology: inflection describes how words relate to lexemes, while lexeme formation describes the relations among members of a morphological family, through instantiations of lexeme formation rules. The type *syn-sign* on the other hand delimits the domain of syntax: phrases consist of words and other phrases. Notice how the status of words as the interface between morphology and syntax is captured by their position in a multiple inheritance hierarchy.

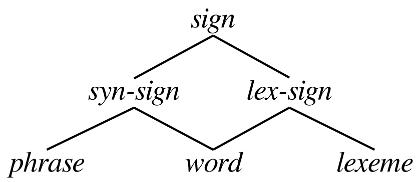

Figure 25: A standard HPSG hierarchy of signs

	1SG	2SG	3SG	1PL	2PL	3PL	stem 1	stem 2	stem 3
LAVER ‘wash’	lav	lav	lav	lavɔ̃	lave	lav	lav	lav	lav
FINIR ‘finish’	fini	fini	fini	finisɔ̃	finise	finis	finis	finis	fini
BROYER ‘grind’	bʁwa	bʁwa	bʁwa	bʁwajɔ̃	bʁwaje	bʁwa	bʁwaj	bʁwa	bʁwa
BOIRE ‘drink’	bwa	bwa	bwa	byvɔ̃	byve	bwav	byv	bwav	bwa

Table 3: Present indicative sub-paradigms and partial stem spaces of 4 French verbs

In section 3.1 we have followed the practice of pedagogical presentations of HPSG such as Sag et al. (2003) and assumed that the phonological form taken by lexemes, like that of words and phrases, is characterised by a single phonological representation under the attribute PHON. This however disregards the prevalence of morphomic stem allomorphy (see among many others Aronoff 1994; Maiden 2005, and the papers collected in Bonami 2012). Since Bonami and Boyé (2006), it has become customary in HPSG work on morphology to assume that lexemes do not have a unique PHON but carry instead a *stem space*, a vector of possibly distinct stem allomorphs; different inflectional or derivational processes then pick one coordinate of the vector as their formal base.

For concreteness let us consider a subset of French morphology. French verbs distinguish up to three stem allomorphs in the present indicative, as illustrated in Table 3. We follow the indexing scheme of Bonami and Boyé (2006), and label ‘stem 1’ the default stem used in the indicative present 1PL and 2PL and in the imperfective, ‘stem 2’ the stem used in the present 3PL, and ‘stem 3’ the stem used in the present SG.

The stem space can be modelled through a list-valued attribute STEMS carried by lexemes and lexemes alone. In the view of Bonami and Boyé (2006), the length of the stem space is characteristic of a part of speech: they assume a length 12 stem space for French verbs, but a length 2 step space for adjectives. Inflection rules then need to pick out a particular stem for use in the realisation of a paradigm cell. In the context of Information-based Morphology as characterised above, this is achieved by a rule of stem introduction that picks out one specific indexed stem as the phonology of a particular morph. As an illustration, Figure 26 shows a rule selecting the second element on the stem space as the realisation of lexeme identity in the context of the present 3PL and realises it as a morph in position 0.

It is important to realise that the attribute STEMS is intended to *replace* PHON for lexemes: in general, there is no single phonological form that could be said to be the phonology of a lexeme. In this context then, lexeme formation rules derive one stem space from another. Bonami and Boyé (2006) lay out the formal consequences of that situation. Figure 27 presents an adapted version of their rule for deriving adjectives in *-eur/-euse* from verbs. Note that the adjectival stem spaces has two elements, corresponding to the default masculine form and the default feminine form.[17] These two stems are both deduced from the first stem of the base

[17] The dual stem space is motivated among other things by suppletive adjectives such as *vieux* ‘old’: M.SG /vjø/,

$$\begin{bmatrix} \text{MUD} & \left\{ \begin{bmatrix} \textit{lid} & \\ \text{STEMS} & \left\langle [\ ], \boxed{1}, \ldots \right\rangle \end{bmatrix} \right\} \\ \text{MS} & \left\{ \textit{prs, 3pl,} \ldots \right\} \\ \text{MPH} & \left\{ \begin{bmatrix} \text{PH} & \boxed{1} \\ \text{PC} & 0 \end{bmatrix} \right\} \end{bmatrix}$$

Figure 26: A sample rule of stem selection in French conjugation

verb, correctly capturing the appropriate stem for examples like *la fièvre laveuse / finisseuse / broyeuse / buveuse* ‘the washing / finishing / grinding / drinking fever’.

$$\begin{bmatrix} \text{STEMS} & \left\langle \boxed{1}\text{+œʁ}, \boxed{1}\text{+øz} \right\rangle \\ \text{CAT} & A \\ \text{SEM} & \begin{bmatrix} \text{IND} & \boxed{x} \\ \text{RESTR} & \left\{ \begin{bmatrix} \textit{typically-rel} & \\ \text{SOA} & \boxed{2} \end{bmatrix} \right\} \end{bmatrix} \\ \text{M-DTRS} & \left\langle \begin{bmatrix} \text{STEMS} & \left\langle \boxed{1}, \ldots \right\rangle \\ \text{CAT} & V \\ \text{SEM} & \begin{bmatrix} \text{RESTR} & \left\{ \boxed{2} \begin{bmatrix} \textit{agentive-rel} & \\ \text{ACT} & \boxed{x} \end{bmatrix} \right\} \end{bmatrix} \end{bmatrix} \right\rangle \end{bmatrix}$$

Figure 27: Lexeme formation rule for French agentive *-eur/-euse* adjectives

Crucially, other lexeme formation rules select another stem of the input verb (Desmets and Villoing, 2009; Tribout, 2010). Likewise, this example illustrates an extreme situation that Bonami and Boyé (2006) call ‘derived irregularity’: both stems in the output need to be explicitly determined by the lexeme formation rule, as the allomorphic relation between those two stems is irregular from the point of view of the inflection systems. In simpler cases where a derived lexeme obeys some regular inflection pattern, a single stem needs to be explicitly specified by rule, and the rest of the stem space is deduced from generalisations over regular stem spaces stated in the lexical hierarchy.

3.4 Relation to other morphological frameworks

By relying both on a sign-based architecture and on inheritance hierarchies, the framework for morphological analysis described in this chapter bears a striking resemblance to two other well-established frameworks, namely Construction Morphology (Booij 2010, this volume) and Network Morphology (Brown and Hippisley 2012; Hippisley, this volume). Here we briefly comment on the historical relations between these approaches and the differences between them.

F.SG /vjɛj/. In M.SG *liaison* contexts, a complex stem selection rule decides which stem should be used. Further derivation from adjectives typically proceeds from stem 2.

The line of work on morphology in HPSG presented in this chapter can be seen as both a predecessor[18] to and a formally explicit variant of Construction Morphology. Constructional schemata as defined by Booij are direct analogues of underspecified lexical entries such as (8) above which embed a base without specifying its lexical identity; individual lexical entries such as 7b correspond to Booij's 'individual words'; the analogue of Booij's 'instantiation' relation is just the relation between a (lexical) leaf type (the instance) and a non-leaf type (the 'schema'). The relation between 'schemata' and 'sub-schemata' is likewise directly captured in terms of a subtype relation between non-leaf types, as exemplified e.g. in Figures 9 and 11.

One superficial difference between the view of lexeme formation presented here and that of Booij (2010) lies in the fact that lexeme formation rules and lexicalised complex words are integrated in a single lexical hierarchy. This is however a rather superficial difference—and in fact, Sag (2012) adopts a minor variant of the view presented in this section with separate hierarchies of lexemes and of morphological constructions licensing these lexemes. The one ingredient of Construction Morphology with no parallel in the HPSG view of lexeme formation is the notion of a second-order schema capturing paradigmatic relations beyond that between a base and its derivative (van Marle, 1984; Becker, 1993; Bochner, 1993). This however seems to be a contingent matter that is more due to the interests of practitioners of HPSG morphology than to limitations of the framework. Indeed, hierarchies of collections of signs in the same morphological family would constitute a natural generalisation of the HPSG view of word formation capturing Bochner's notion of a cumulative pattern.

Network Morphology shares with the HPSG approaches to morphology described in this section commitments to formal explicitness, lexicalism, and the use of inheritance hierarchies. The main differences between the two frameworks result from their respective formal underpinnings: where HPSG is based on the logic of typed feature structures and usually relies on monotonic inheritance, Network Morphology theories are written in DATR (Evans and Gazdar, 1996), a language for describing collections of paths (rather than feature structures) and designed to implement default inheritance.

In practice, both languages are expressive enough that the same morphological analyses can often be implemented in one or the other frameworks, although this is not always obviously apparent given different presentation conventions. Consider again the description of *-able* adjectives in section 3.1.1 above. Many of the types in the HPSG type hierarchy in Figure 9 are motivated by the monotonic nature of inheritance: because some *-able* adjectives have unexpected syntax or semantics, constraints need to be distributed in appropriately restricted subtypes of the general type *-able*. Following Pollard and Sag (1994, 17-21), individual lexemes must belong to a single leaf type in the hierarchy, which makes necessary the introduction of the open subtype *X-able* of *reg-able* to distinguish lexicalised from non-lexicalised derivatives. A natural Network Morphology implementation of the same analysis would thus rely on a flatter hierarchy, with a single node `Able` listing all properties of regular *-able* adjectives,

[18]Cross-fertilisation between construction grammar and HPSG is evident since the mid-1990s, as witnessed e.g. by work such as Sag (1997), Kay (2002), or the papers collected in Webelhuth et al. (1999), culminating in the design of *Sign-based construction grammar* (Boas and Sag, 2012), which is a variant of both HPSG and (Berkeley) Construction Grammar. Jean-Pierre Koenig's (1994) dissertation, which predates by a decade publications branding themselves as *Construction Morphology*, explicitly aimed at elaborating a credible approach to morphology within Construction Grammar, and introduced much of the analytic apparatus presented in this chapter. The relation between HPSG and Construction Grammar was close enough that the relevant parts of Koenig (1994) could be transparently ported to HPSG in Koenig (1999). Note also the contemporary elaboration, within HPSG, of constructional analyses of periphrastic inflection and lexeme formation (Ackerman and Webelhuth, 1998) and idioms (Riehemann, 2001).

and irregular cases treated as nodes partially inheriting from this, as sketched in Figure 28. The execution is different, but arguably, the underlying analysis is the same.

```
Able:                                 Lavable:
<> == Lfr                             <> == Able
<phon> == "<base phon>" ə b ə l       <base> == Laver:<>.
<cat> == adjective
<sem ind> == "<base sem rel act>"     Fiable:
<sem rel> == possible                 <> == Able
<sem rel soa> == "<base sem rel>"     <base> == Se_fier:<>
<base cat> == verb                    <base val> == NP PP[à].
<base val> == NP NP
<base sem reltype> == agentive.       Adorable:
                                      <> == Able
                                      <base> == Adorer:<>
                                      <sem rel> == necessary
                                      <sem rel soa> == "<base sem rel>".
```

Figure 28: A Network Morphology analysis of French *-able* adjectives parallel to the HPSG analysis if Figure 9

The one distinct advantage of an HPSG approach to morphology that is not shared by Network Morphology is reliance on a formalism that is in wide use for the modelling of syntax, as well as lexical and compositional semantics. This has practical, methodological and theoretical consequences. On a practical level, HPSG morphology may rely on a preexisting toolbox of formal mechanisms and analytic strategies. On a methodological level, morphological analyses are readily interfaced with fully explicit analyses in syntax and semantics, making the falsifiablity of hypotheses on interface issues a concrete reality. On a theoretical level, the uniformity of the formalism assumed in HPSG makes a strong claim about the nature of human language, namely that symbolic linguistic knowledge can be described in a most general fashion using a single decriptive device, namely unification of typed feature structures, organised into monotonic inheritance hierarchies.

4 Conclusions

In this chapter we gave a broad outline of the status of morphology in constraint-based lexicalist approaches to grammar, and presented in more detail a family of approaches to morphological phenomena within HPSG that attempt to take stock of the state of the art in descriptive and theoretical morphology to elaborate a morphological framework that takes full advantage of the monotonic constraint-based architecture of HPSG and the descriptive devices it offers. As the examples discussed above hopefully make clear, such an approach has four major advantages. First, the high expressiveness of the typed feature structure formalism makes it possible to capture linguistic intuitions rather directly. Second, monotonic inheritance hierarchies prove successful in capturing morphological patterns at different levels of abstraction, while eschewing arbitrary decisions about what constitutes a default or non-default pattern. Third, the existence of carefully designed theories of syntax, lexical semantics, and phonology based on the same formalism helps making falsifiable claims on morphology that do not rely on unarticulated hypotheses about neighbouring domains. Fourth and finally, the same holds in the opposite direction: claims about strong lexicalism within syntactic theories need to be substantiated by realistic articulated morphological analyses; the morphological framework outlined in section 3 provides such a substantiation.

A sociological observation of the field of contemporary linguistics shows that much less effort is generally devoted to constructing formally explicit analyses within morphology than is typical in syntax or semantics. This seems to be caused at least in part by a feeling, among both morphologists and formal grammarians, that morphology is simple enough that detailed formalisation is not worth the effort. We hope the present chapter will have shown otherwise: just as in other sub-fields, formal explicitness is an indispensable guide to both description and theory construction about complex morphological systems, and different formal architectures lead to different theories of morphology.

References

Abeillé, A., Bonami, O., Godard, D., and Tseng, J. (2003). 'The syntax of french *à* and *de*: an hpsg analysis'. In *Proceedings of the ACL-SIGSEM Workshop on the Linguistic Dimensions of Prepositions*. 133–144.

Abeillé, A. and Godard, D. (2002). 'The syntactic structure of French auxiliaries'. *Language*, 78:404–452.

Ackerman, F. and Bonami, O. (in press). 'Systemic polyfunctionality and morphology-syntax interdependencies'. In A. Hippisley and N. Gisborne (eds.), *Defaults in Morphological Theory*. Oxford: Oxford University Press.

Ackerman, F., Stump, G. T., and Webelhuth, G. (2011). 'Lexicalism, periphrasis and implicative morphology'. In R. D. Borsley and K. Börjars (eds.), *Non-Transformational Syntax: Formal and Explicit Models of Grammar*. Wiley-Blackwell, 325–358.

Ackerman, F. and Webelhuth, G. (1998). *A Theory of Predicates*. Stanford: CSLI Publications.

Anderson, S. R. (1992). *A-Morphous Morphology*. Cambridge: Cambridge University Press.

Andrews, A. D. (1990). 'Unification and morphological blocking'. *Natural Language and Linguistic Theory*, 8:507–557.

Aronoff, M. (1994). *Morphology by itself*. Cambridge: MIT Press.

Aronoff, M. and Xu, Z. (2010). 'A realization optimality-theoretic approach to affix order'. *Morphology*, 20:388–411.

Barwise, J. and Perry, J. (1983). *Situations and attitudes*. Cambridge: MIT Press.

Becker, T. (1993). 'Back-formation, cross-formation, and 'bracketing paradoxes' in paradigmatic morphology'. In G. Booij and J. van Marle (eds.), *Yearbook of Morphology 1993*. Dordrecht: Kluwer, 1–25.

Bender, E. and Sag, I. A. (2000). 'Incorporating contracted auxiliaries in english'. In R. Cann, C. Grover, and P. Miller (eds.), *Grammatical interfaces in HPSG*. Stanford: CSLI Publications, 17–32.

Bertram, R., Schreuder, R., and Baayen, R. H. (2000). 'The balance of storage and computation in morphological processing: The role of word formation type, affixal homonymy, and productivity'. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 26:489–511.

Bickel, B., Banjade, G., Gaenzle, M., Lieven, E., Paudya, N. P., Rai, I. P., Manoj, R., Rai, N. K., and Stoll, S. (2007). 'Free prefix ordering in Chintang'. *Language*, 83:43–73.

Bird, S. (1995). *Computational Phonology. A Constraint-based Approach*. Studies in Natural Language Processing. Cambridge: Cambridge University Press.

Bird, S. and Ellison, T. M. (1992). 'One level phonology: Autosegmental representations and rules as finite state automata'. Tech. Rep. 51, University of Edinburgh, Center for Cognitive Science.

Bird, S. and Klein, E. (1994). 'Phonological analysis in typed feature systems'. *Computational Linguistics*, 20:455–491.

Boas, H. and Sag, I. A. (eds.) (2012). *Sign-Based Construction Grammar*. Stanford: CSLI Publications.

Bochner, H. (1993). *Simplicity in Generative Morphology*. Berlin: Mouton de Gruyter.

Bonami, O. (2011). 'Reconstructing HPSG morphology'. In *18th International Conference on HPSG*. Seattle.

Bonami, O. (ed.) (2012). *Word Structure 5.1: Stems in inflection and lexeme formation*. Edinburgh: Edinburgh University Press.

Bonami, O. (2015). 'Periphrasis as collocation'. *Morphology*, 25:63–110.

Bonami, O. and Boyé, G. (2002). 'Suppletion and stem dependency in inflectional morphology'. In F. Van Eynde, L. Hellan, and D. Beerman (eds.), *The Proceedings of the HPSG '01 Conference*. Stanford: CSLI Publications, 51–70.

——— (2006). 'Deriving inflectional irregularity'. In *Proceedings of the 13th International Conference on HPSG*. Stanford: CSLI Publications, 39–59.

——— (2007). 'French pronominal clitics and the design of Paradigm Function Morphology'. In *Proceedings of the fifth Mediterranean Morphology Meeting*. 291–322.

Bonami, O. and Crysmann, B. (2013). 'Morphotactics in an information-based model of realisational morphology'. In S. Müller (ed.), *Proceedings of HPSG 2013*. Stanford: CSLI Publications, 27–47.

Bonami, O. and Samvelian, P. (2008). 'Sorani Kurdish person markers and the typology of agreement'. In *13th International Morphology Meeting*. Vienna.

——— (2009). 'Inflectional periphrasis in Persian'. In S. Müller (ed.), *Proceedings of the HPSG 2009 Conference*. Stanford: CSLI Publications, 26–46.

——— (2015). 'The diversity of inflectional periphrasis in Persian'. *Journal of Linguistics*, 51:327–382.

Booij, G. (2010). *Construction morphology*. Oxford: Oxford University Press.

Borsley, R. D. (1999). 'Weak auxiliaries, complex verbs and inflected complementizers in Polish'. In R. D. Borsley and A. Przepiórkowski (eds.), *Slavic in Head-Driven Phrase Structure Grammar*, Studies in Constraint-Based Lexicalism, chap. 2. Stanford: CSLI Publications, 29–59.

Borsley, R. D. and Börjars, K. (eds.) (2011). *Non-Transformational Syntax: Formal and Explicit Models of Grammar*. New York: Wiley-Blackwell.

Bresnan, J. (1982). 'The passive in lexical theory'. In J. Bresnan (ed.), *The mental representation of grammatical relations*. Cambridge: MIT Press, 3–86.

——— (2001). *Lexical-functional syntax*. Oxford: Basil Blackwell.

Bresnan, J. and Mchombo, S. (1995). 'The lexical integrity principle: evidence from Bantu'. *Natural Language and Linguistic Theory*, 13:181–254.

Broadwell, G. A. (2008). 'Turkish suspended affixation is lexical sharing'. In *Proceedings of the LFG08 Conference*.

Brown, D. and Hippisley, A. (2012). *Network Morphology: a defaults based theory of word structure*. Cambridge: Cambridge University Press.

Carpenter, B. (1992). *The Logic of Typed Feature Structures with Applications to Unification-based Grammars, Logic Programming and Constraint Resolution*, vol. 32 of *Cambridge Tracts in Theoretical Computer Science*. New York: Cambridge University Press.

Carstairs, A. (1987). *Allomorphy in Inflection*. London: Croom Helm.

Clements, G. N. (1985). 'The geometry of phonological features'. *Phonology Yearbook*, 2:223–252.

Copestake, A., Flickinger, D., Pollard, C., and Sag, I. (2005). 'Minimal recursion semantics: an introduction'. *Research on Language and Computation*, 3:281–332.

Crysmann, B. (1999). 'Morphosyntactic paradoxa in Fox'. In G. Bouma, E. Hinrichs, G.-J. Kruiff, and R. Oehrle (eds.), *Constraints and Resources in Natural Language Syntax and Semantics*, Studies in Constraint-Based Lexicalism. Stanford: CSLI publications, 41–61.

——— (2003a). 'Clitic climbing revisited'. In J.-B. Kim and S. Wechsler (eds.), *Proceedings of the 9th International Conference on Head-driven Phrase Structure Grammar, Kyung Hee University, Seoul, 5–7 August, 2002*. Stanford: CSLI Publications, 67–89.

——— (2003b). *Constraint-based Coanalysis. Portuguese Cliticisation and Morphology–Syntax Interaction in HPSG*. No. 15 in Saarbrücken Dissertations in Computational Linguistics and Language Technology. Saarbrücken: Computational Linguistics, Saarland University and DFKI LT Lab.

——— (2005). 'Syncretism in German: a unified approach to underspecification, indeterminacy, and likeness of case'. In S. Müller (ed.), *Proceedings of the 12th Int'l Conference on Head-driven Phrase Structure Grammar (HPSG), Aug 22–24, Lisbon*. Stanford: CSLI publications, 91–107.

——— (2006). 'Floating affixes in Polish'. In S. Müller (ed.), *Proceedings of the 13th International Conference on Head-Driven Phrase Structure Grammar*. Stanford: CSLI Publications, 123–139.

——— (2009). 'Underspecification and neutrality: a unified approach to syncretism'. In *Proceedings of the Joint Conference on Formal Grammar and Mathematics of Language (FG-MOL) 2005, Aug 5–7, Edinburgh*. Stanford: CSLI publications, 1–12.

——— (2010a). 'A coanalysis approach to Polish past tense agreement'. In A. Nolda and O. Teuber (eds.), *Syntax and Morphology Multi-dimensional*, Interface Explorations. Berlin: Mouton de Gruyter, 77–100.

——— (2010b). 'Discontinuous negation in Hausa'. In S. Müller (ed.), *Proceedings of the Workshop on Morphology and Formal Grammar at the 17th International Conference on Head-Driven Phrase Structure Grammar (HPSG 2010)*. CSLI Publications, 269–287.

——— (in press). 'Inferential-realisational morphology without rule blocks: an information-based approach'. In A. Hippisley and N. Gisborne (eds.), *Defaults in Morphological Theory*. Oxford: Oxford University Press, 32pp.

Crysmann, B. and Bonami, O. (2012). 'Establishing order in type-based realisational morphology'. In S. Müller (ed.), *Proceedings of HPSG 2012*. Stanford: CSLI publications, 123–143.

——— (2015). 'Variable morphotactics in Information-Based Morphology'. *Journal of Linguistics*, 52. DOI: S0022226715000018.

Dalrymple, M., Holloway King, T., and Sadler, L. (2009). 'Indeterminacy by underspecification'. *Journal of Linguistics*, 45:31–68.

Dalrymple, M. and Kaplan, R. M. (2000). 'Feature indeterminacy and feature resolution'. *Language*, 76:759–798.

Daniels, M. W. (2002). 'On a type-based analysis of feature neutrality and the coordination of unlikes'. In F. Van Eynde, L. Hellan, and D. Beermann (eds.), *Proceedings of the 8th International Conference on Head-Driven Phrase Structure Grammar*. Stanford: CSLI Publications, 137–147.

Desmets, M. and Villoing, F. (2009). 'French VN lexemes: morphological compounding in HPSG'. In *Proceedings of the HPSG 2009 Conference*. Stanford: CSLI Publications, 89–109.

Ellison, T. M. (1985). 'OT, finite-state representations, and procedurality'. In *Proceedings of the Conference on Formal Grammar*. Barcelona.

Engdahl, E. and Vallduví, E. (1994). 'Information packaging and grammar architecture: A constraint-based approach'. In E. Engdahl (ed.), *Integrating information structure into constraint-based and categorial approaches*. Amsterdam: ILLC, 39–79. DYANA-2 Report R.1.3.B.

Erjavec, T. (1994). 'Formalizing realizational morphology in typed feature structures'. In G. Bouma and G. v. Noord (eds.), *Proceedings of the fourth CLIN meeting*. Groningen, 47–58.

Evans, R. and Gazdar, G. (1996). 'Datr: a language for lexical knowledge representation'. *Computational Linguistics*, 22:167–216.

Flickinger, D. (1987). *Lexical rules in the hierarchical lexicon*. Ph.D. thesis, Stanford University.

Fokkens, A., Poulson, L., and Bender, E. M. (2009). 'Inflectional morphology in Turkish VP coordination'. In S. Müller (ed.), *Proceedings of HPSG 2009*. 110–130.

Frank, A. and Reyle, U. (1995). 'Principle based semantics for HPSG'. In *Proceedings of EACL*. 9–16.

Frank, A. and Zaenen, A. (2004). 'Tense in LFG: Syntax and morphology'. In L. Sadler and A. Spencer (eds.), *Projecting Morphology*. Stanford: CSLI Publications.

Ginzburg, J. and Sag, I. A. (2000). *Interrogative Investigations. The Form, Meaning, and Use of English Interrogatives*. Stanford: CSLI Publications.

Goldsmith, J. A. (1976). *Autosegmental Phonology*. Ph.D. thesis, MIT.

Goodman, M. W. and Bender, E. M. (2010). 'What's in a word? refining the morphotactic infrastructure in the LinGO Grammar Matrix customization system'. Poster presented at the HPSG 2010 Conference.

Hathout, N., Plénat, M., and Tanguy, L. (2003). 'Enquête sur les dérivés en *-able*'. *Cahiers de grammaire*, 28:49–90.

Hinrichs, E. and Nakazawa, T. (1989). 'Subcategorization and VP structure in German'. In *Aspects of German VP structure*. Universität Tübingen.

Hockett, C. F. (1954). 'Two models of grammatical description'. *Word*, 10:210–234.

Huygue, R. and Tribout, D. (2015). 'Noms d'agent et noms d'instrument: le cas des déverbaux en *-eur*'. *Langue française*, 185:99–112.

Ingria, R. J. P. (1990). 'The limits of unification'. In *Proceedings of the Twenty-Eigth Annual Meeting of the Association for Computational Linguistics*. 194–204.

Kaplan, R. M. and Bresnan, J. (1982). 'Lexical-functional grammar: a formal system for grammatical representation'. In J. Bresnan (ed.), *The mental representation of grammatical relations*. Cambridge: MIT Press, 173–281.

Kaplan, R. M. and Kay, M. (1994a). 'Regular models of phonological rule systems'. *Computational Linguistics*, 20:331–378.

——— (1994b). 'Regular models of phonological rule systems'. *Computational Linguistics*, 20:331–378.

Karttunen, L., Kaplan, R. M., and Zaenen, A. (1992). 'Two-level morphology with composition'. In *Proceedings of Coling 1992*. 141–148.

Kasper, R. and Rounds, W. (1986). 'A logical semantics for feature structures'. In *Proceedings of the 24th Annual Meeting of the Association of Computational Linguistics (ACL)*. Morristown, NJ: ACL.

Kathol, A. (1994). 'Passives without lexical rules'. In J. Nerbonne, K. Netter, and C. J. Pollard (eds.), *German in HPSG*. Stanford: CSLI Publications, 237–272.

——— (1999). 'Agreement and the syntax-morphology interface in hpsg'. In G. M. Green and R. D. Levine (eds.), *Studies in contemporary phrase structure grammar*. Cambridge: Cambridge University Press.

——— (2000). *Linear Syntax*. Oxford: Oxford University Press.

Kay, P. (2002). 'An informal sketch of a formal architecture for construction grammar'. *Grammars*, 5:1–19.

King, P. (1989). *A Logical Formalism for Head-Driven Phrase Structure Grammar*. Ph.D. thesis, University of Manchester.

Kiparsky, P. (1982). 'Lexical phonology and morphology'. In *Linguistics in the morning calm*. Seoul: Hansin, 3–91.

——— (1985). 'Some consequences of lexical phonology'. *Phonology Yearbook*, 2:83–136.

Koenig, J.-P. (1994). *Lexical underspecification and the syntax-semantics interface*. Ph.D. thesis, University of California, Berkeley.

——— (1999). *Lexical relations*. Stanford: CSLI Publications.

Koenig, J.-P. and Jurafsky, D. (1994). 'Type underspecification and on-line type construction'. In *Proceedings of WCCFL XIII*. 270–285.

Koskenniemi, K. (1983a). *Two-Level Morphology: A General Computational Model for Word-form Recognition and Production*. Ph.D. thesis, University of Helsinki.

——— (1983b). *Two-level morphology: A general computational model for word recognition and production*. Ph.D. thesis, University of Helsinki.

Krieger, H.-U. (1994). 'Derivation without lexical rules'. In C. J. Rupp, M. A. Rosner, and R. Johnson (eds.), *Constraints, Language, and Computation*. Academic Press. Previously published in *Proceedings of the Workshop on Constraint Propagation, Linguistic Description, and Computation*, IDSIA Working Paper No. 5, Lugano, November, 1991. Also published as DFKI Research Report RR-93-27.

——— (1996). *TDL — A Type Description Language for Constraint-Based Grammars*, vol. 2 of *Saarbrücken Dissertations in Computational Linguistics and Language Technology*. Saarbrücken: DFKI GmbH.

Krieger, H.-U. and Nerbonne, J. (1993). 'Feature-based inheritance networks for computational lexicons'. In T. Briscoe, A. Copestake, and V. de Paiva (eds.), *Default Inheritance Within Unification-Based Approaches to the Lexicon*. Cambridge: Cambridge University Press, 90–136. Also published as Report RR-91-31, DFKI, Saarbrücken.

Krieger, H.-U., Pirker, H., and Nerbonne, J. (1993). 'Feature-based allomorphy'. In *Proceedings of the thirty-first meeting of the Association for Computational Linguistics*. 140–147.

Kupść, A. and Tseng, J. (2005). 'A new hpsg approach to polish auxiliary constructions'. In *Proceedings of HPSG 2005*. Stanford: CSLI Publications, 253–273. http://cslipublications.stanford.edu/HPSG/6/.

Leben, W. (1973). *Suprasegmental Phonology*. Ph.D. thesis, MIT.

Levy, R. and Pollard, C. (2002). 'Coordination and neutralization in hpsg'. In F. Van Eynde, L. Hellan, and D. Beermann (eds.), *Proceedings of the 8th International Conference on Head-Driven Phrase Structure Grammar*. Stanford: CSLI Publications, 221–230.

Luschützky, H. C. and Rainer, F. (2013). 'Instrument and place nouns: a typological and diachronic perspective'. *Linguistics*, 51:1301–1359.

Luutonen, J. (1997). *The variation of morpheme order in Mari declension*. Helsinki: Suomalais-ugrilainen Seura.

Maiden, M. (2005). 'Morphological autonomy and diachrony'. In G. Booij and J. van Marle (eds.), *Yearbook of Morphology 2004*. Dordrecht: Kluwer, 137–175.

Malouf, R. (2000). 'A head-driven account of long-distance case assignment'. In R. Cann, C. Grover, and P. Miller (eds.), *Grammatical Interfaces in Head-driven Phrase Structure Grammar*, Studies in Constraint-based Lexicalism. Stanford: CSLI Publications, 201–214.

Maxwell III, J. T. and Kaplan, R. M. (1993). 'The interface between phrasal and functional constraints'. *Computational Linguistics*, 19:571–589.

Meurers, W. D. (2002). 'On expressing lexical generalizations in HPSG'. *Nordic Journal of Linguistics*, 24.

Miller, P. (1992). *Clitics and constituents in Phrase Structure Grammar*. New York: Garland.

Miller, P. and Sag, I. A. (1997). 'French clitic movement without clitics or movement'. *Natural Language and Linguistic Theory*, 15:573–639.

Monachesi, P. (1999). *A lexical approach to Italian cliticization*. Stanford: CSLI Publications.

——— (2000). 'Clitic placement in the Romanian verbal complex'. In B. Gerlach and J. Grijzenhout (eds.), *Clitics in Phonology, Morphology and Syntax*, vol. 36 of *Linguistik Aktuell/Linguistics Today*. John Benjamins, 255–293.

Müller, S. (2002). *Complex Predicates: Verbal Complexes, Resultative Constructions, and Particle Verbs in German*. Stanford: CSLI Publications.

——— (2003). ‘The morphology of german particle verbs: Solving the bracketing paradox’. *Journal of Linguistics*, 39:275–325.

Namer, F. and Villoing, F. (2008). ‘Interpréter les noms déverbaux: quelle relation avec la structure argumentale du verbe base? le cas des noms en *-oir* du français’. In *Actes du premier Congrès Mondial de Linguistique Française*. 1551–1569.

Nordlinger, R. (1998). *Constructive Case*. Stanford: CSLI Publications.

Nordlinger, R. and Sadler, L. (forthcoming). ‘Morphology in HPSG and LFG’. In J. Audring and F. Masini (eds.), *The Oxford Handbook of Morphological Theory*. Oxford: Oxford University Press.

Noyer, R. (1992). *Features, positions and affixes in autonomous morphological structure*. Ph.D. thesis, MIT.

Orgun, C. O. (1996). *Sign-Based Morphology and Phonology*. Ph.D. thesis, University of California, Berkeley.

Penn, G. (1999). ‘A generalized-domain-based approach to serbo-croatian second position clitic placement’. In G. Bouma, E. Hinrichs, G.-J. Kruijff, and R. T. Oehrle (eds.), *Constraints and resources in natural language semantics*, Studies in constraint-based lexicalism. Stanford: CSLI Publications, 119–136.

Perlmutter, D. M. (1988). ‘The split morphology hypothesis: evidence from Yiddish’. In M. Hammond and M. Noonan (eds.), *Theoretical morphology: approaches in modern linguistics*. San Diego: Academic Press, 79–100.

Plag, I. (1999). *Morphological productivity*. Berlin: Mouton de Gruyter.

Pollard, C. and Sag, I. A. (1987). *Information-based syntax and semantics*. Stanford: CSLI Publications.

——— (1994). *Head-driven Phrase Structure Grammar*. Stanford: CSLI Publications; The University of Chicago Press.

Prince, A. and Smolensky, P. (1993). ‘Optimality theory: constraint interaction in generative grammar’.

Reyle, U. (1993). ‘Dealing with ambiguities by underspecification’. *Journal of Semantics*, 10:123–179.

Richter, F. (2000). *A Mathematical Formalism for Linguistic Theories with an Application in Head-Driven Phrase Structure Grammar*. Ph.D. thesis, Universität Tübingen.

Richter, F. and Sailer, M. (2003). ‘Basic concepts of lexical resource semantics’.

Riehemann, S. (1993). *Word Formation in Lexical Type Hierarchies: A Case Study of bar-Adjectives in German*. Master’s thesis, Universität Tübingen.

——— (1998). ‘Type-based derivational morphology’. *Journal of Comparative Germanic Linguistics*, 2:49–77.

——— (2001). *A constructional approach to idioms and word formation*. Ph.D. thesis, Stanford University.

Rogers, J. (1998). *A descriptive approach to language-theoretic complexity*. CSLI Publications.

Round, E. (2013). *Kayardild morphology and syntax*. Oxford: Oxford University Press.

Ryan, K. M. (2010). ‘Variable affix order: Grammar and learning’. *Language*, 86:758–791.

Sadler, L. and Nordlinger, R. (2004). ‘Relating morphology to syntax’. In L. Sadler and A. Spencer (eds.), *Projecting Morphology*. CSLI Publications, 159–183.

——— (2006). ‘Case stacking in realizational morphology’. *Linguistics*, 44:459–488.

Sadler, L. and Spencer, A. (2001). ‘Syntax as an exponent of morphological features’. In G. Booij and J. van Marle (eds.), *Yearbook of Morphology 2000*. Dordrecht: Kluwer, 71–96.

Sag, I. A. (1997). ‘English relative clause constructions’. *Journal of Linguistics*, 33:431–484.

——— (2003). ‘Coordination and underspecification’. In *Proceedings of the 9th HPSG Conference*. Stanford: CSLI Publications, 267–291.

——— (2012). ‘Sign-based construction grammar: An informal synopsis’. In H. Boas and I. A. Sag (eds.), *Sign-Based Construction Grammar*. Stanford: CSLI Publications, 69–202.

Sag, I. A., Wasow, T., and Bender, E. (2003). *Syntactic theory. A formal introduction*. Stanford: CSLI Publications, 2nd edn.

Samvelian, P. and Tseng, J. (2010). 'Persian object clitics and the syntax-morphology interface'. In *Proceedings of HPSG 2010*. Stanford: CSLI Publications, 212–232.

Scobbie, J. (1991). *Attribute-Value Phonology*. Ph.D. thesis, University of Edinburgh.

Scobbie, J. M. (1993). 'Constraint violation and conflict from the perspective of declarative phonology'. *Canadian Journal of Linguistics*, 38:155–167.

Simpson, J. (1991). *Warlpiri morphosyntax: a lexicalist approach*. Dordrecht: Kluwer.

Smolensky, P. and Legendre, G. (2006). *The harmonic mind: from neural computation to optimality-theoretic grammar*. Cambridge: MIT Press.

Spencer, A. (2003). 'Periphrastic paradigms in Bulgarian'. In U. Junghanns and L. Szucsich (eds.), *Syntactic Structures and Morphological Information*. Berlin: Mouton de Gruyter, 249–282.

——— (2013). *Lexical relatedness: a paradigm-based model*. Oxford: Oxford University Press.

Stump, G. T. (1993). 'Position classes and morphological theory'. In G. E. Booij and J. van Marle (eds.), *Yearbook of Morphology 1992*. Kluwer, 129–180.

——— (2001). *Inflectional Morphology. A Theory of Paradigm Structure*. Cambridge: Cambridge University Press.

Tribout, D. (2010). *Les conversions de nom à verbe et de verbe à nom en français*. Ph.D. thesis, Université Paris Diderot.

——— (2012). 'Verbal stem space and verb to noun conversion in French'. *Word Structure*, 5:109–128.

Trueswell, J. and Tanenhaus, M. K. (1994). 'Toward a lexical framework of constraint-based syntactic ambiguity resolution'. In C. Clifton, L. Frazier, and K. Rayner (eds.), *Perspectives on sentence processing*. Hillsdale, NJ: Lawrence Erlbaum, 155–179.

van Marle, J. (1984). *On the Paradigmatic Dimension of Morphological Creativity*. Dordrecht: Foris.

Villoing, F. (2002). *Les mots composés VN du français: réflexions épistémologiques et propositions d'analyse*. Ph.D. thesis, Université Paris X-Nanterre.

Vincent, N. and Börjars, K. (1996). 'Suppletion and syntactic theory'. In *Proceedings of the first LFG conference*.

Walther, M. (1999). *Deklarative Prosodische Morphologie*, vol. 399 of *Linguistische Arbeiten*. Tübingen: Niemeyer.

Webelhuth, G., Kœnig, J.-P., and Kathol, A. (eds.) (1999). *Lexical and constructional aspects of linguistic explanation*. Stanford: CSLI Publications.

Wechsler, S. and Zlatić, L. (2003). *The Many Faces of Agreement*. Stanford: CSLI Publications.

Wescoat, M. (2002). *On lexical sharing*. Ph.D. thesis, Stanford University.

——— (2007). 'Preposition-determiner contractions: an analysis in optimality-theoretic lexical-functional grammar with lexical sharing'. In *Proceedings of the LFG07 Conference*.

Zwicky, A. (1991). 'Some choices in the theory of morphology'. In R. Levine (ed.), *Formal Grammar: Theory and Implementation*. Vancouver: University of British Columbia, 327–371.