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Compounding in the Slot Structure Model

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Finding the range of possible semantic relations between the constituents of a compound has been an elusive goal. The current paper presents a model of compound formation with the goal of demonstrating how the meaning of a compound is built from that of its constituents, and the relations between them, within the framework of the Slot Structure Model (SSM) (Benavides 2003; 2009; 2010; 2022). The SSM is a constraint-based model of morphology that is based on percolation of both syntactic and semantic features and on slot structure, which organizes the information in the lexical entries of words and affixes. The SSM is partly based on the dual-route model of morphology. It is shown that analyzing compound formation using SSM brings with it several advantages, including a more comprehensive explanation of how the semantics of compounding works; a more systematic way to determine the headedness of a compound; the ability to explain the generativity of compounds on the basis of the actual and potential information contained in the lexical entries of the components; and the simplification of the interpretation of compounds, due to the structure of the lexical information involved in the determination of compound meaning. The analysis of compounds based on Conceptual Semantics is taken as a basis for comparison. The current paper provides an account for a wide range of compound types, including NN, NA, AN, VN, and AA, in English, Spanish and German. Example compounds to support the analysis have been obtained from corpora and other sources.

1 Introduction

An account of the semantics of compounding has been one of the most elusive undertakings in morphological research. As Jackendoff (2010) points out, scholars have despaired at finding the range of possible semantic relations (or basic functions) between the constituents of a compound. The current paper presents a fully developed model of compound formation, set within the framework of the Slot Structure Model (SSM) (Benavides 2003; 2009; 2010; 2022), a constraint-based model of morphology that is based on percolation of both syntactic and semantic features and on slot structure, which organizes the information in the lexical entries of words and affixes. (See a detailed explanation of slot structure in § 3.) The SSM is partly based on the dual-route model (Pinker 2006; Pinker 1999; Pinker & Ullman 2002). The goal of the paper is to demonstrate how the meaning of a compound is built from that of its components, and the relations between them, using the SSM framework.

It is shown that analyzing compound formation using SSM brings with it several advantages, including a more comprehensive explanation of how the semantics of compounding works; a principled, more systematic way to determine the headedness of a compound, regardless of the language; the ability to explain the generativity of compounds on the basis of the actual and potential information contained in the lexical entries of the constituents; and the simplification of the interpretation of compounds, not only because of the notation, but also due to the structure inside the lexical entries involved in the determination of compound meaning. Importantly, SSM achieves all this employing the same machinery that is already used for derivation, with some enhancements, including the enrichment of lexical entries, to produce a flexible, generative mechanism that accounts for the semantics of a wide range of compounds.

Jackendoff's (2010) analysis of compounds based on Conceptual Semantics is taken as a basis for comparison. Part of the reason for this is Lieber's (2019) observation that Jackendoff's "account is far more successful than earlier attempts at modeling the semantics" of compounds, in that his theory allows for the free generation of new meanings. It is shown in § 4 that the treatment of compounding in SSM also allows for this free generation of meaning. An important difference between SSM and Jackendoff's (2010) analysis is that while Jackendoff (2010) restricted the discussion to NN compounds, the current paper provides an account for a wider range of compound types, including NN, NA, AN, VN, and AA. The analysis is based on English, Spanish and German compounds, but it should be applicable to compounds in other languages. The paper thus achieves a wider coverage of the data than other current approaches that deal with the semantics of compounding, including Jackendoff (2009; 2010; 2016) and Toquero-Pérez (2020), who analyze NN compounds, and Schlücker (2016), who discusses AN compounds.

According to Jackendoff (2010), the class of possible meaning relations between the two nouns in a compound is the product of a generative system which is based on basic functions, that is, meaning relations such as X_2 is SIMILAR TO Y_1 for *kidney*$_1$ *bean*$_2$. This paper shows how the lexical entries of the two constituents of a compound provide the basic information that gives rise to the generativity of compound meaning, incorporating basic functions into lexical entries. An indefinite number of semantic functions can be generated based on the lexical information of the compound constituents. The unification of the two lexical entries contributes to making it a generative process.

The paper is organized as follows: §2 discusses the basic semantic functions and schemas proposed by Jackendoff (2009; 2010; 2016). In §3, an explanation of how the SSM works is presented, followed by the analysis of compound formation in SSM, in § 4. Exocentric compounds are also discussed in this section. Example compounds to support the analysis have been obtained from the Corpus del Español (CDE, Davies 2002), the iWeb corpus (Davies 2018), Jackendoff (2010), Toquero-Pérez (2020), Lang (2013), Moyna (2011), and Schlücker (2016). For example, Toquero-Perez (2020) analyzed over 200 Spanish NN compounds, and exemplified close to 100 of those in his paper. Each one of those compounds was examined for this study, and the semantics for all of them can be accounted for using the SSM. A table appears in the Appendix with compounds taken from corpora that are examined and illustrated in § 4. More information about these compounds is provided in that section.

2 Basic semantic functions and schemas

Before introducing the basic functions, it is important to provide more information about why Jackendoff's analysis based on semantic functions is taken as a basis for comparison in the current study, as well as discuss some background information on Conceptual Semantics (Jackendoff 1983; 1990; 2002; 2007), the framework under which the analysis of basic functions is couched. As noted above, part of the reason for using Jackendoff's analysis as a basis for comparison is Lieber's (2019) observation regarding the superiority of Jackendoff's account in modeling the semantics of compounds when compared to earlier attempts. According to Lieber (2019), prior accounts have in common that they propose a finite set of semantic relationships, in contrast to Jackendoff's model, which allows for the free generation of new meanings. For example, in earlier generative/transformational approaches to compounding, such as Lees (1960) and Levi (1978), the attempt was made to treat the semantics of compounds as fully determinate, and to characterize compound meaning using a fixed list of semantic functions such as MADE OF, USED FOR, and SIMILAR TO.

Lieber (2019) argues that the key problem with such treatments is that, because a potentially infinite number of relationships between compound constituents can be found, it is impossible to arrive at a constrained, finite list of functions. Similarly, Jackendoff (2010) argues that no theory that derives the meaning of compounds just from words and (syntactic) structure—including early approaches such as Lees (1960), Levi (1978), and Selkirk (1982)—can adequately account for the semantics of compounds. This is so because the class of possible meaning relations between the constituents of a compound is the product of a generative system, so it is impossible to enumerate them.

More recently, ten Hacken (2016) sees Jackendoff's system based on semantic functions as an elaboration of the idea of Levi's (1978) proposal, but without the precisely specified number of readings. Ten Hacken (2016) also compares Jackendoff's model with Štekauer's (1998; 2009) onomasiological analysis, where onomasiological types (OTs), such as Action and Location, are used in the decision process to determine the name to be used for a particular concept. Ten Hacken (2016) notes that the semantic representations in Jackendoff's framework are much more detailed than Štekauer's, which can be explained by the different aims. Jackendoff represents semantic structure and turns to word formation/compounding because it has semantic implications, while Štekauer accounts for the naming process in word formation and uses those aspects of semantics that guide the decision process leading to a name for the concept. Ten Hacken (2016) notes as well that Štekauer's OTs can be legitimately used as classes of word formation, but not specifically of compounds. Thus, in these two respects, Jackendoff's model seems to be more adequate for the semantic analysis of compounds.

Conceptual Semantics (Jackendoff 1983; 1990; 2002; 2007; 2010) is a mentalist framework that is deeply concerned with details of word meaning and how these interact with composition of phrase meanings. At the same time, it incorporates a significant amount of what is usually called pragmatics: aspects of meaning that are not encoded in word meanings or in relations conveyed directly by syntactic structure. Some of its motivating questions are: What is the formal structure of our knowledge of the world? How is this structure expressed linguistically? In particular, adds Jackendoff (2010), Conceptual Semantics is concerned with the totality of meaning, not just the part composed directly from syntactic structure, so-called linguistic semantics. With respect to compounding, the basic intuition is that the meaning of a compound is a function of the meanings of its components. This is the case for compositional compounds only. As Jackendoff (2010) notes, compounds with unpredictable meanings, like idioms, are stored units. Speakers store thousands of lexicalized compounds with idiosyncratic or metaphorical meanings (e.g. *tall tale*, *puppy love*, *carbon footprint*, *black box* [airplanes], *cold war* [politics]).

However, compounds cannot all be stored in the lexicon; new compounds can be built on the fly and understood on a single exposure. Jackendoff (2010) cites *politician tycoon*, *aid inflow*, *locality pay*, and *spring seepage*. There is also the frequent coining of compounds in particular discourse situations, for instance *bike girl* being used for a girl who left her bike in the vestibule (Jackendoff 2010). These occasion-specific formations are also known as *ad hoc concepts* (e.g. *Ferrari woman* "woman in the news whose will stipulated that she be buried in her Ferrari") (Wilson 2017; Horn 2017). Speakers can easily produce and understand such compounds, which have exactly a frequency of one. The semantics of one-off compounds such as these can be determined as in the model proposed in §4, regardless of their frequency or the cooccurrence of their components with other words. According to Jackendoff (2010), there is also evidence from acquisition for the compositionality of many new compounds: children begin understanding novel compounds and coining their own between about 2½ and 3½. In short, compounding must include a productive rule system.

Thus, the problem regarding compositional compounds is, given two nouns N_1 and N_2 meaning X_1 and Y_2, respectively, what is the function $F(X_1, Y_2)$ that yields the meaning of the compound [N_1 N_2]? Posed in terms of SSM, the question is, given two words that come together in the mind of a speaker, what happens to the information stored in those words when they unify? As seen in § 3, the basic functions are provided by and operate inside the lexical entries of the constituents of a compound.

Jackendoff (2009; 2010; 2016) presents a list of the most prominent basic functions for English compounds. Toquero-Pérez (2020) made modifications to that list, for example by adding the functions PROPER FUNCTION (PF) and ARGUMENT. The combination of the two lists is shown in **Table 1**. According to Jackendoff, these seem rather plausible as functions that are readily available pragmatically. These functions are used in the analysis of compounds in § 4. (Note: X is the meaning of N_1, Y is the meaning of N_2.)

	Function	**Paraphrase**	**Example**
1.	CLASSIFY (X_1,Y_2)	‘N_1 classifies N_2’	beta cell Leyden jar
2.	PF (X_1,Y_2)	‘N_2 whose PF is to function as/act N_1’	attack helicopter stew beef
3.	ARGUMENT Y_2(X_1) (Rev.)	‘(a/the) N_2 of/by N_1’	helicopter attack collar size
4.	SIMILAR (X_1,Y_2)	‘an N_2 similar to N_1’	kidney bean pie chart
5.	KIND (X_1,Y_2) (Rev.)	‘N_1 is a kind of N_2’	pine tree ferryboat
6.	BE (X_1, AT/IN/ON/ Y_2) (LOCATION) (Rev.)	‘N_1 located at/in/on N_2’	lake house inkpad November rain
7.	COMP (X_1,Y_2) (Rev.)	‘N_2 is composed of N_1’	meatball sheet metal

(Contd.)

	Function	Paraphrase	Example
8.	MADE (X_1, FROM Y_2) (Rev.)	'N_2 made from N_1'	coconut oil rubber tree
9.	PART OF (X_1,Y_2) (Rev.)	'N_2 is part of N_1'	doorknob wheelchair cinnamon roll
10.	CAUSE (X_1,Y_2)	'N_2 caused by N_1'	diaper rash sunburn
11.	MAKE (X_1,Y_2) (Rev.)	'N_1 makes N_2'	spider poison silkworm
12.	SERVES-AS (Y_2, X_1)	'N_2 that serves as N_1'	guard dog extension cord
13.	HAVE (X_1,Y_2) (Rev.)	'N_2 that has N_1'	glamour girl gangster money
14.	PROTECT (X_1,Y_2 FROM Z)	'N_2 protects N_1 from something'	lifeboat flea collar
15.	BE (Y_2,X_1)	'N_2 is (also) an N_1'	boy king singer-songwriter
16.	BOTH (X_1,Y_2)	'both N_1 and N_2'	boy king politician-tycoon

Table 1: List of basic functions (adapted from Jackendoff 2016: 27–30 and Toquero-Pérez 2020: 9).

Note that several of these basic functions, if not all, can form part of the core meaning of simplex nouns (and other words), and may sometimes coincide with proper functions. For instance, the basic function PROTECT is the proper function of *shield* (shield$_1$ = [SHIELD; [PF (X_1 PROTECT FROM Y)]], where Y can be certain weapons); bread is composed of flour (COMP); a sedan is a type of car (CLASSIFY); an oak is a KIND of tree; a finger is a PART of a hand; and pheromones are MADE BY some animals. Notice as well how the basic function PF is shown inside the lexical entry for *book* in (1) below, an example from Jackendoff (2010). This fact is important for the analysis of compounding in § 4, because the functions are shown as embedded in the slot structure of lexical entries, not as part of a schema (see below).

It is important to note as well that the basic functions do not correspond, in large part, to classifications of compounds based on grammatical relations (such as subordinative, attributive, and determinative) presented in studies such as Scalise and Bisetto (2009). A single basic function usually overlaps with more than one classification type, and vice versa. For example, *back yard*, which is attributive, is characterized by the function LOCATION, while *street seller*, also characterized by LOCATION, is subordinative. On the other hand, several subordinative compounds can be characterized by different basic functions: *apple cake* – MADE FROM; *sun glasses* – PROTECT FROM; and *wind mill* – CAUSE. The same is the case with attributive compounds: *sword fish* – SIMILAR; and *atomic bomb* – CLASSIFY (or CAUSE). This happens with all such classification systems (e.g. Bloomfield 1933; Bauer 2008; Fernández-Domínguez 2019) because they are not based on semantic relations. For this reason, compound classification systems based on grammatical relations do not seem to be strictly relevant for the current study. This finds support in Scalise and Bisetto's (2009) observation that classifications based on grammatical relations should be kept separate from all other criteria, such as internal structure or the semantic relation between constituents. Ten Hacken (2016) notes as well that when the discussion on compounds concerns the interpretation of the relationship between their components, it is not necessary to know for each expression which category of compound it belongs to. That is, there is no reason to distinguish rigorously delimited categories of compounds.

For a noun that denotes an artifact such as *book*, the proper function is part of its lexical entry, as in (1). (The somewhat simplified notation of (1) is used in the rest of the present paper.) Note that the term *proper function* can be equated with the *telic quale* from Generative Lexicon (GL) theory (Pustejovsky 1995, Pustejovsky & Ježek 2016), which encodes information on purpose and function in a lexical entry. According to Jackendoff (2010), the telic quale specifies the proper function of an object. Generative Lexicon theory proposes other qualia for lexical entries, including *formal*, *constitutive*, and *agentive*, and these are considered to be a part of the core meaning of lexical items. According to Pustejovsky (1995) and Pustejovsky & Ježek (2016), the qualia is the mechanism used in GL to represent the core meaning of words. This insight is incorporated into SSM, and qualia, including the telic quale (that is, Proper Function) are part of the CORE slot in SSM entries (see more details in § 3).

(1) book_1 = [BOOK; [PF (PERSON READ Y_1)]]

(adapted from Jackendoff 2010)

According to Jackendoff (2010), with the use of these functions, establishing the semantic structure of a compound N_1N_2 involves two factors: designating a head – in English, N_2 – and determining the semantic relation between N_1 and N_2. There are two routes for connecting things semantically to N_2. First, N_1 can be an argument of N_2, as in *violin player*. These are so-called synthetic compounds (or argumental compounds (cf. Lieber 2019); the general schema appears in (2a). Second (2b), N_1 can be part of a modifier of N_2.

(2) N-N compound schemata (or constructions) (Jackendoff 2010)

a. *Argument schema*:
$[N_1\ N_2] = [Y_2\ (\ldots, X_1, \ldots)$
'a N_2 by/of/… N_1'

b. *Modifier schema*:
$[N_1\ N_2] = [Y_2^{\alpha}; [F\ (\ldots, X_1, \ldots, \alpha, \ldots)]]$
'an N_2 such that F is true of N_1 and N_2'

The basic functions can fill in *F* in (2b) to build compound meanings, as in (3a, b), where LOC and COMP are basic functions filling in *F*; *F* can also be filled out from material in the lexical entry of N_2, as in (3c). It is also possible to use material from N_1, as in *cannonball*, where the notion of shooting comes from the proper function of *cannon*.

(3) a. $\text{window}_1\ \text{seat}_2 = \text{SEAT}_2\ ; [Y_2\ \text{LOC AT WINDOW}_1]$
b. $\text{felafel}_1\ \text{ball}_2 = \text{BALL}_2; [Y_2\ \text{COMP FELAFEL}_1]$
c. $\text{coffee}_1\ \text{cup}_2 = \text{CUP}_2; [\text{PF (HOLD (COFFEE}_1, \text{IN } Y_2))]$

(adapted from Jackendoff 2010)

As in these examples, Jackendoff (2009; 2010; 2016) repeatedly uses the terms *fill out*, *filling out*, *filled out* or *filled in* when describing how compound meaning is determined through the use of functions and schemas. As shown in § 4, this filling out fits in naturally with SSM, because both the use of material from the lexical entries of the compound constituents and the filling out of functions occurs inside the lexical entries of the constituents in SSM.

3 The Slot Structure Model (SSM)

Because compounding in SSM occurs via unification of constituents, as in derivation, where slot structure and percolation play a key role, it is important to provide a somewhat detailed explanation of how the SSM works. For additional details, see Benavides (2003; 2009; 2010; 2022).

The SSM is an approach to morphology based in part on Lexical Conceptual Structure (LCS) (Jackendoff 1990; 2002; Rappaport & Levin 1988; 1992) that explains the process of [base + affix] unification in regular word formation in Spanish (e.g. *demoli + cion* [*demolición* 'demolition']) and other languages, and is crucially based on the notion of lexical entries instantiated in a slot structure. Employing the mechanisms of subcategorization/selection (subcat/select) and percolation, already available in the generative framework (cf. Lieber 1992; 1998; Pinker 2006; Pinker 1999; Pinker & Ullman 2002; Huang & Pinker 2010), the model unifies all the processes that take place during the formation of a complex word (e.g. *plega + ble* [*fold + able*] 'foldable').

Crucial to the SSM is that percolation, subcat/select, and slot structure, acting in concert determine the structure and content of the lexical entries of derivatives (i.e. words formed by morphological derivation, such as *demoli + ción*) and allow for predictions to be made about the behavior of groups of features in the formation of a word. Percolation in particular, as shown by Pinker (1999) and Pinker & Ullman (2002), is key to account for compositionality in word formation. Huang & Pinker (2010) call percolation *information-inheritance* and stress the need for this mechanism in morphology, both in inflection and word formation. For example, percolation is needed to explain why certain verbs and nouns that presumably should be irregular, are consistently regularized by speakers (e.g. ***flied** out instead* of ***flew** out*; ***ringed** the city* instead of *rang*; *low lifes* rather than **low lives*; *wolfs* (instances of wolfing down food) rather than **wolves*). (See a detailed explanation and demonstration of percolation in § 3).

With these and many other examples, as well as with corpus studies and psycholinguistic/neurolinguistic experiments, Pinker (1999; 2006), Huang & Pinker (2010) and Pinker & Ullman (2002) show empirically that when an affix is a part of a complex structure (sometimes acting as the head), percolation is inherently involved (in both inflection and word formation). Importantly, as seen below, there is no ordering in the application of percolation; thus, word formation in the SSM is constraint-based and non-procedural, except for unification.

In addition to accounting for regular derivation, the SSM adequately accounts for regular inflection (e.g. *libro + s* 'book + s,' *beb + o* [drink-1sg, pres.] 'I drink'), as well as the regular derivational morphology of several languages genetically unrelated to Spanish (Mam, Turkish, Swahili), which suggests that the notions of percolation, subcat/select, slot structure and the LCS may be universal constructs. The original formulation of the SSM (Benavides 2003; 2009) was supported by the analysis of over 1,250 derivatives (types) formed with more than fifty productive Spanish affixes. More recently (Benavides 2022), a corpus study was conducted to gather data on the Spanish suffix *-ble*.

The SSM is a concatenative approach that accounts for regular morphology, but it accounts for irregular morphology as well through the adoption of Pinker's (2006; 1999) dual-route model (also known as the dual-process model or words-and-rules theory; see also Pinker & Ullman 2002; Huang & Pinker 2010). The dual-route model posits that while regular forms (e.g. *work + er*, Sp. *completa + mente* 'completely') are computed by combinatorial rules, irregular, semiproductive, or unpredictable forms (e.g. *strength*, *salut + at + ion* vs. **salut + ion*, Sp. *resoluble* vs. **resolvible* (reg.) 'solvable') have to be memorized and are stored in a sort of analogical (associative, relational) network that is a part of the lexicon and implements lexical redundancy rules. Thus, when speakers hear or produce a complex word, they first attempt to form a derivative via the regular route (using SSM principles, see below), but if an irregular form already exists for that concept, the regular route is blocked and the irregular form stored in the lexicon takes over. The search for the stored form and the operation of the rule work in parallel, until one of them "wins." It is important to note that while frequent regular forms may be redundantly stored in the lexicon (Jackendoff 2013, Plag & Baayen 2009), derivatives can be formed on the fly and be used just for the needs of the moment, without having to be stored. (See Ciaccio et al. 2023 and Abugaber et al. 2023 et al. for more recent studies that provide support for the dual-route model, on the basis of EEG/ERP data.)

Alegre & Gordon (1999) provide evidence that supports the dual-route model as applied to derivational affixation. Their results suggest that derivational morphology, much like inflectional morphology, shows dissociations between rule-based and associative generalization mechanisms. They found that words formed with certain (less productive) suffixes (*-ion*, *-al*, *-ity*, *-ous*, *-ic*) exhibit cluster (or gang, i.e. associative) effects, just like irregular inflected words (e.g. *ring-rang*, *sing-sang*, *drink-drank* generalize to *spling-splang*), while words formed with more productive suffixes (*-ize*, *-en*, *-ness*, *-able*, *-ment*, *-er*), much like regular inflection do not display such effects.

As further support for the dual-route model as applied to derivation, Vannest, Polk & Lewis (2005) found that decomposable (i.e. regular) derived words in English (formed with the suffixes *-ness*, *-less*, *-able*) showed increases in activity in regions of interest (Broca's area and the basal ganglia) relative to nondecomposable (i.e. irregular) suffixed words (formed with *-ity*, *-ation*), suggesting that, in accordance with the dual-route model, while regular forms are accessed from the mental lexicon as separate morphemes (base and affix), irregulars are accessed as whole units.

The details and application of the SSM are explained in the following sections.

3.1 Slot structure

Arranging features in a lexical entry in the form of a slot structure rather than just listing the features, allows for predictions to be made about the behavior of groups of features during and after derivation. It will be seen that the slot structure of bases and affixes as proposed here is a crucial factor in the derivational process because it helps determine the structure of the lexical entries of outputs (derived words). The information contained in lexical items is organized into groups of features that act as information blocks that percolate as units to the branching node. This arrangement of blocks of information located within their respective slots constitutes the "slot structure" of each lexical item.

It is generally assumed (cf. Grimshaw 1990) that verbs, adjectives and some nouns have argument structures. Since these lexical items subcategorize and select for arguments, they must have, in addition to blocks that contain their ontological, categorial, and core semantic information (see below), blocks that contain syntactic subcategorization and selectional information. Inasmuch as verbs, adjectives, nouns and affixes differ idiosyncratically in their featural content and argument structure, they must also differ in their slot structure. Thus, the idiosyncratic information contained in lexical items is what determines their slot structure.

The idea of a slot structure containing idiosyncratic information is compatible with the notion of an LCS. The LCS is the place in the lexical entry of an item where the syntactically relevant semantic content of the item is encoded (cf. Rappaport & Levin 1988; Jackendoff 1983; 1990; Speas 1990). The LCS is defined as the decomposition of the meaning of a word into conceptual primitives (e.g. primitive predicates such as CAUSE and GO) which are related to arguments that occupy slots and are also characterized by means of conceptual primitives (e.g. ontological categories such as [THING] and [EVENT]). As Kornfilt & Correa (1993) point out, the LCS captures the core aspects of the meaning of a lexical item (that is, its core meaning), not the whole range of meaning associated with the item (i.e., encyclopedic information is not included in the LCS). For example, (4) is the LCS of the verb *put*.

(4) LCS of *put*
PUT: [$_{\text{EVENT}}$ CAUSE ([THING], [$_{\text{EVENT}}$ GO ([THING], [AT [PLACE]])])]
(adapted from Jackendoff 1990)

In SSM, the LCS is represented in the form of semantic features within feature blocks which may percolate, along with blocks containing morphosyntactic features, to the mother node in a derivative. The percolation of feature blocks from a head and a non-head to a branching node (as illustrated below) explains the layering of meaning as well as the addition or deletion of semantic primitives and slots that Lieber (1992) describes as taking place in the LCS when affixation occurs. Lieber's (1992) own notions of Head and Backup Percolation (as modified below) can handle the percolation of all types of features, including semantic features and those related to argument structure.

Due to space limitations, the detailed composition of the contents of the slots and blocks that make up slot structure, the rationale for the content of each slot, and how these components are organized in a lexical entry, are not shown here. Please see Benavides (2022) for details.

In the next sections the implementation of the SSM is demonstrated.

3.2 Derivations

3.2.1 Modified Feature Percolation Conventions

Before showing derivational trees that illustrate how the SSM works, it is necessary to discuss percolation in some detail. Lieber's (1992) Percolation Conventions, whose formulation was influenced by Selkirk (1982) and Di Sciullo & Williams (1987), are taken as the basis for percolation in the SSM. The major modifications to Lieber's (1992) Percolation Conventions made in the present model consist of the incorporation of semantic features, and the organization of lexical information into slot structures. Because of this, the Modified Feature Percolation Conventions proposed here (5) involve a re-definition of the features that are allowed to percolate by Head and Backup Percolation, in answer to Lieber's (1992: 77) question of "what features percolate, [and] where features are allowed to percolate from."

(5) Modified Feature Percolation Conventions

a. Head Percolation: The affix (the head) percolates its non-subcat/selectional information (i.e. its CATEGORIAL, CORE and ARGUMENT slots and blocks) to the branching node.

b. Secondary Percolation: All the information blocks of the base (i.e. the CATEGORIAL, CORE, ARGUMENT, and PARTICIPANT blocks) percolate to the branching node and attempt to occupy slots. Once a slot has been occupied, a percolating information block may occupy that slot as long as it has compatible features (i.e. either morphosyntactic or semantic). If a percolating block does not find an empty or compatible slot, it may not occupy any slots in the output, and is discarded.

First, notice that Backup Percolation has been relabeled Secondary Percolation. The term "backup" implies that certain features percolate after other features (head features) have percolated. However, as conceived in (5), the process of percolation does not imply any ordering in its application but rather reflects the idea that Head Percolation takes precedence over the percolation of features from the base (Secondary Percolation).

Second, the notion of "compatible features" encoded in Secondary Percolation needs to be elaborated on. Aside from having to belong to the same type (morphosyntactic or semantic), features are compatible if they can coexist in a single slot without contradicting or canceling each other out. For example, since an entity cannot be both an [EVENT] and a [THING], nor a noun and a verb at the same time, the CATEGORIAL blocks of a base and a suffix cannot occupy the same slot. On the other hand, since the features that may be stored in the CORE slot (classemes, semes, general features, and primitive predicates) do not necessarily contradict each other, features from different CORE blocks may coexist in the same slot. Thus, "doubly-filled" slots (as when two CORE blocks occupy the same slot in a derivative) are allowed when there is feature compatibility. Recall as well from § 2 that the basic function PF (equivalent to the telic quale in Generative Lexicon theory), is part of the core meaning of lexical items, and thus it is information that is stored in the CORE slot.

Secondary Percolation entails that the CORE, ARGUMENT, and PARTICIPANT blocks of the base may occupy slots in the output after having percolated. The CATEGORIAL block of the base will not occupy the CATEGORIAL slot of the output because that slot is already filled by the CATEGORIAL block of the affix. The CATEGORIAL block of the base cannot occupy any other slots (i.e. the CORE or ARGUMENT slots) because of feature incompatibility. The CATEGORIAL block of the base therefore cannot occupy a slot in the output and is discarded. If the slot structure of the suffix provides only one or no ARGUMENT slots, some of the ARGUMENT blocks of the base will not find any slots to occupy and will be discarded as well.

Head Percolation entails that the affix imposes its slot structure on the output, with the final location of each block in the derivative being dictated by this slot structure. That is, once head features percolate (within information blocks), they determine what features of the base and affix will occupy what slots in the branching node. The slot structure of the affix (the head) thus constrains the possible lexical content (i.e. slot structure) of the output. The changes in argument structure (e.g. suppression of an argument) are included in the changes brought about by the imposition of the slot structure of the affix on the output. Thus, there is no need to explain this suppression by employing rules which state, for example, that the affix “absorbs” or “binds” an argument. The suppression of arguments follows from the operation of percolation on slot structure. Head Percolation thus allows for predictions to be made about the feature composition and slot structure of the derivative, making the notion of “head” in this concatenative model a central concept.

Crucially, a head is characterized by the fact that it imposes its categorial features on the output, and affects argument structure by adding arguments or contributing to their suppression. It follows that the non-head in a derivative can neither impose its categorial features on the output nor bring about changes in argument structure. In addition, the notion of head and the mechanism of Head Percolation give rise to the prediction that the features of the non-head (the base) do not overrule the features of the head (the affix) in the output. In sum, the whole process just described can be conceived of as the percolation of both morphosyntactic and semantic information in parallel fashion from the head and non-head to the branching node, with the features of the head preempting those of the non-head. Because of the percolation of the features of the head, one can predict what features of the non-head can percolate.

The application of feature percolation is demonstrated with derivational trees in the following section.

3.2.2 Derivational trees

The trees in this section show derivations with Spanish bases and suffixes. They demonstrate that when the information in the lexical entries of bases and affixes is organized into slot structures, predictions can be made about the organization of information in derivatives, including their argument structure.

3.2.2.1 Suppression of arguments

What follows is a description of **Figure 1**, a derivational tree with the suffix *-dor*. The slots in the output that contain information blocks that have percolated to the branching node by Head

Percolation have been set in boldface. To facilitate interpretation, arrows have been placed in lexical entries to indicate the filling of a given slot in the output by a given block. For example, in **Figure 1**, the arrow in the CORE block of the base signals that that block occupies the CORE slot in the output.

As noted above, the LCS, which contains semantic information and from which argument and aspectual structure derive, is itself contained within slot structure. In the derivational trees below, the shaded areas represent the LCS of each lexical item. The CATEGORIAL slots, which contain syntactic information, are a part of slot structure but not of the LCS. The slots in each lexical entry are ordered vertically rather than horizontally for convenience and ease of interpretation, in order to facilitate the representation of the unification of the lexical entries of the base and suffix. However, lexical entries in SSM, as in **Figure 1** and the remaining trees below, are not just a list of features; the slots represent the internal structure of lexical items. A mere list of features would not have the necessary structure to account for the operations that take place during unification, as explained below. Whether represented vertically, horizontally, or in other ways, lexical entries in SSM are organized triplets of semantic, syntactic and phonological information. In the trees, slots for arguments that are empty have been labeled but not numbered. In order to make clearer the relation between the conventional (horizontal) LCS representation and the vertical one illustrated in the trees below, consider the LCS (in simplified notation) of *colar* 'sift' in (6) as compared to the LCS in **Figure 1**.

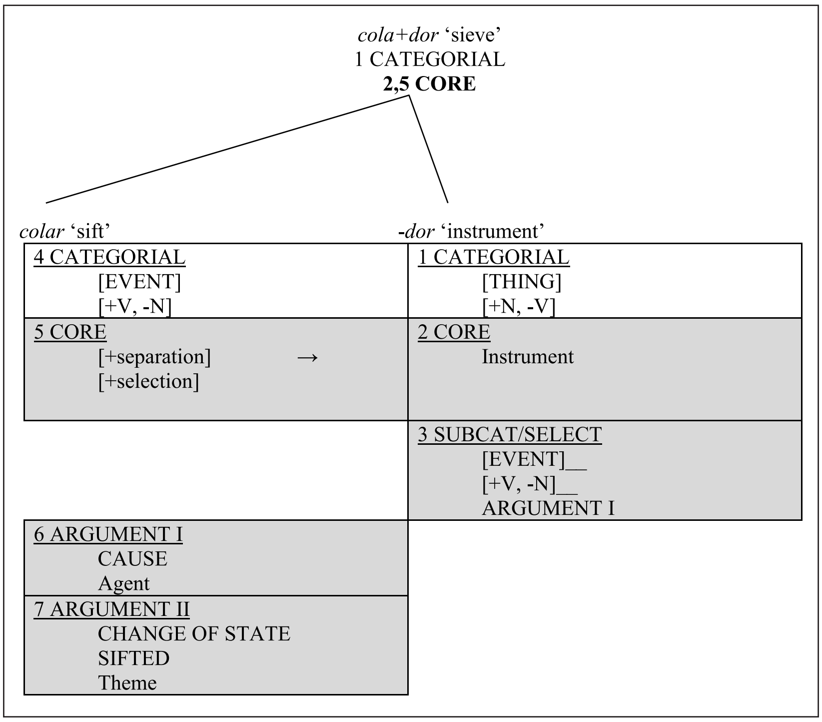


Figure 1: V > N **-dor** derivation.

(6) colar ‘sift’: [x CAUSE [y BECOME SIFTED]]

The first subevent, with its accompanying argument, [x CAUSE], corresponds to block 6 in the tree, while the second subevent, [y BECOME SIFTED], corresponds to block 7. Block 5, the CORE block, as its name indicates provides the core meaning of *sift*. Features such as CHANGE OF STATE, in slot 7, represent the association between arguments and aspectual features. The terms Agent and Theme are used merely as labels for arguments. The same relation between the horizontal LCS and the vertical LCS should be interpreted for the remaining trees below.

Since the verb (*colar*) is an event composed of two subevents, each one of the two ARGUMENT blocks of the base represents an argument associated with a subevent. Even though the two ARGUMENT blocks percolate to the branching node by Secondary Percolation, they cannot occupy slots in the output because the output, being a noun without an argument structure, does not have ARGUMENT slots. The failure of the two ARGUMENT blocks of the base to find slots in the output represents the operation where the LCS of the suffix completely “deletes” or “suppresses” the argument structure of the base. This is one of the ways in which Head and Secondary Percolation determine the interaction between the LCSs of the lexical items that participate in a derivation and determine the argument structure of the output. Note further that the CORE slots of the base and suffix contain the non-argumental semantic features of the LCS, to give the meaning ‘instrument for sifting,’ which is the core definition of a sieve. Notice as well that the derivative, *colador*, now has the categorial features of the suffix (Noun), due to Head Percolation.

The question may arise whether the noun *colador* (or its equivalent in Hispanic America, *coladora*) actually lacks nominal arguments (as shown in **Figure 1**), unlike, say, *driver*, which can appear in phrases such as *driver of a truck*, retaining the ARGUMENT II from the base, expressed as a prepositional object. A search in the Web/Dialects section of the Corpus del Español (CDE, Davies 2002), which contains 2 billion words of Spanish taken from web pages, showed no instances of *coladora* with a prepositional object, and while *colador* ‘sieve’ did appear in the corpus in phrases such as *colador de café* ‘coffee strainer,’ they were very few; the vast majority of examples were cases where the noun that follows the preposition is a modifier, not an argument, of the main noun (e.g. *colador de metal* ‘metallic sieve’). Although one can find forms such as *colador(a) de café* and *colador de pasta* from a Google search, given the corpus results it seems that the word *colador(a)* without arguments is the standard form. However, a polysemous form for this suffix, with a slot for an ARGUMENT II in its entry, can be posited.

Finally, notice in **Figure 1** how the SUBCAT/SELECT block specifies that the suffix may only attach to verbs that have an ARGUMENT I block. This ensures that derivatives formed with, say, unaccusative verbs are ungrammatical (e.g., **caedor* ‘instrument for falling’ < *caer* ‘to fall’ or **gotea + dor* ‘instrument for dripping or for producing drops’ < *gotear* ‘to drip’).

3.2.2.2. Addition Accompanied by Transference of Arguments

Next consider the derivation in **Figure 2**, with the suffix *-izar*. Here the suffix provides a filled ARGUMENT I slot to the output, and the base ARGUMENT II block fills the ARGUMENT II slot of the output.

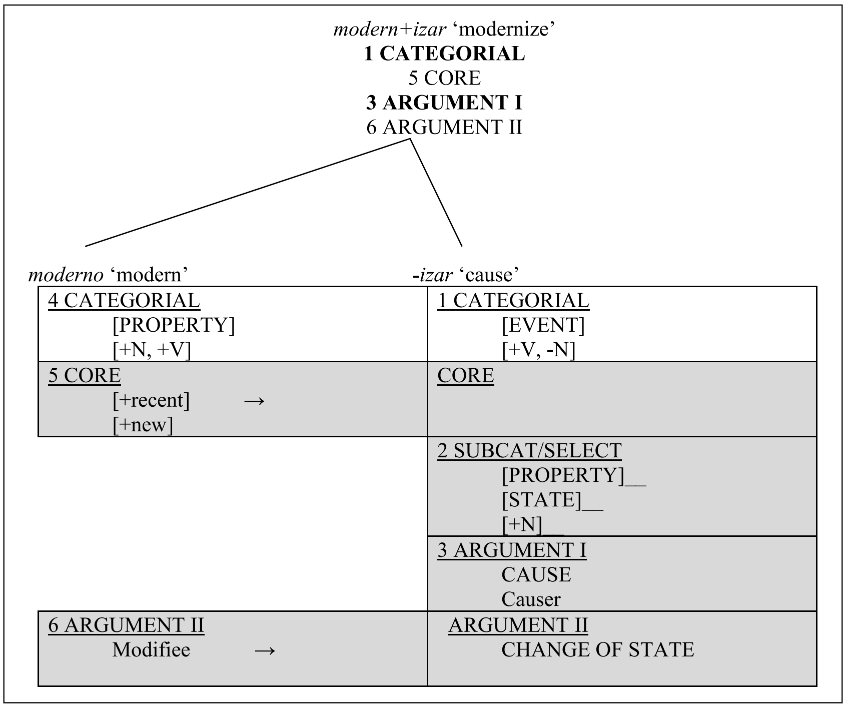


Figure 2: A > V -**izar** derivation.

The single argument of the base, an ARGUMENT II, occupies the ARGUMENT II slot in the output because it remains Proto-Patient-like in the output. This is a case where, on unifying, the LCSs of the base and suffix each contribute one argument to the derivation. Again, Head and Secondary Percolation determine the interaction between LCSs.

The list in (7) summarizes the operations on argument structure that result from derivation, some of which have been illustrated in the trees above. (As in the derivational trees above, the arrows indicate transference by percolation of a base argument to a slot in the output.) Please see Benavides (2003; 2009; 2022) for additional derivational trees.

(7) Summary of operations on argument structure:
Suppression of one or more arguments (**Figure 1**)
Addition of an argument (by the suffix) (**Figure 2**)
ARGUMENT II → ARGUMENT II (**Figure 2**)
ARGUMENT I → ARGUMENT I (not shown)

It is important to point out that even though there is unification of features as part of the process of percolation, percolation goes beyond unification and allows for some features to override and suppress other features, as seen in the derivational trees above. In addition, while unification grammars (Shieber 1986; Hellwig 2004) and slot grammars (McCord 1980) have slots for arguments and complements, unlike SSM, they do not have slots for the rest of the information in a lexical entry. One of the key innovations of SSM is that all the information in a lexical entry is stored in slots, and these slots percolate and determine the meaning of complex words. In turn, a crucial element of this innovation is that each argument and its associated subevent are stored together in a single slot, not separated into their own structures (Argument Structure, Event Structure), and these slots percolate during unification. This enables a more accurate and predictive explanation of the inheritance of arguments and events in derivation and compounding.

The model illustrated above accounts for derivational suffixation, and it has been extended (Benavides 2003; 2009; 2022), using the exact same tools and mechanisms, to other types of affixes (in Spanish and other languages), namely, derivational prefixes, passives, causatives, applicatives, expressive suffixes (e.g. diminutives), inflectional affixes, and parasynthetics. The next section shows how the SSM can be extended to account for the semantics of a wide range of compounds in Spanish and other languages and demonstrates the flexibility of lexical entries organized into a slot structure. This flexible structure, which takes into account pragmatics and world knowledge, was shown in Benavides (2003; 2009; 2022) to apply in the treatment of derivational affixes, causatives and applicatives in languages such as Mam, Turkish, Swahili, Chichewa, Madurese, Malayalam, Chimwi:ni, and Choctaw.

4 Compounding in SSM

As with derivation, compounding in SSM occurs via the unification of the constituents of the compound, with slot structure and percolation playing a key role. Pragmatic information, world knowledge and encyclopedic knowledge are also important factors in determining compound meaning (Jackendoff 2009; 2010), and this is reflected in the SSM analysis presented below. For example, what slots will be relevant for the selection of a given proper function may depend on pragmatics and context. As noted in the introduction, the analysis goes beyond NN compounds and encompasses a wider range of compound types, including NA, AN, VN, and AA, providing a better coverage of the data than other current models.

As seen in § 2, in Jackendoff's (2016) account (see also Schlücker 2016), the schemas for the basic functions can use material from the internal semantic structure of the two nouns, but the schemas are separate, detached from the lexical entries of the constituents. As Toquero-Pérez (2020) notes, in Jackendoff's model, *F* is an external function that establishes the semantic relation between constituents. That is, schemas are a reflection or an abstraction of what is going on inside lexical entries during compound formation. In contrast, in SSM the semantics involved in the functions expressed by the schemas are incorporated into slot structure, due to the content of the lexical entries of the components, as well as the action of unification and percolation. It can be said that the basic functions are integrated into the lexical entries of the constituents, and features in slot structure compose with each other. See diagrams below for exemplification.

In SSM, the basic functions arise by the unification of the lexical entries and by the needs of the speaker creating or interpreting the compound. This is consistent with approaches that see naming as key to word formation and compounding. For example, ten Hacken & Panocova (2024) and ten Hacken (2019) argue that new lexical entries originate due to naming needs; that is, naming is triggered by a naming need. For instance (example not from ten Hacken), say some scientists are trying to create a spherical nanostructure with graphene. However, serendipitously, they create an empty cube or box, which can hold molecules. They are elated and want to give their new invention a name. They decide that it will be a *box*, but they want more details in the name and want to include what it is made of, so they name it a *graphene box*. Note how the basic function *made of* (or COMP) arises due to the need to create a new lexical item. Note also that a word other than *graphene*, say, *quantum*, or the prefix *nano-* could have been selected to add to *box*. An indefinite (or unlimited) number of functions can be generated (Jackendoff 2010), and in SSM the unification of the components is what makes this generative process possible, because the constituent that will be joined to *box* has key features to contribute to the meaning of the compound as a whole.

Note that an unlimited number of functions arises when a given word is potentially combined with many other words to form a compound. When a word combines with only one or two other words, the number of potential meanings of the compound will be lower. For example, the potential functions/meanings for *graphene sphere* and *graphene box* are limited. In addition to 'box/sphere made of graphene,' they could mean 'box/sphere that contains graphene' or 'box/sphere that produces graphene.' However, meanings with other basic functions such as SIMILAR (*'box/sphere that looks like graphene') or KIND (*'box/sphere that is a type of graphene') would be a stretch, or not possible meanings. However, if, as noted above, *box* is combined with *quantum* to form *quantum box*, other functions may arise, including CAUSE if the box produces quantum effects, and so on if *graphene* is replaced with other words.

In addition, the analysis of compounding in SSM shows that lexical entries as represented in SSM are flexible. There is a template for lexical entries, but it is not fixed; different slots may be used depending on the type of word formation or compounding. This flexibility or elasticity of slot structure facilitates the generativity that characterizes compound formation. And this flexibility is not ad hoc; it is based on the actual and potential slots already available in the entries of simplex lexical items.

It is important to emphasize that Jackendoff's (2010) generative system creates an unlimited set of possibilities for basic functions. As noted in § 2, according to Jackendoff (2010), the class of possible meaning relations between the two nouns is the product of a generative system, so it is impossible to enumerate them. This limitless generativity is also a characteristic of the SSM mechanism as applied to compounding.

As noted in § 3, Jackendoff (2010) repeatedly uses the terms *fill out*, *filling out*, *filled out* or *filled in* when describing how the meaning of compounds is determined. This fits in nicely with the SSM notion of blocks of information filling out slots in lexical entries. It makes sense for there to be spaces in lexical entries for this filling out to occur; these spaces are the slots of slot structure in SSM that are key for the formation of compounds, as illustrated in the next section. It is seen that the functions have designated slots, which are filled out just like the other slots, and information from both the head and non-head fills out the slot structure provided by the head for the entire compound.

4.1 Diagrams of compound formation in SSM

The diagrams in this section illustrate the application of SSM principles to compound formation. Recall that Head Percolation entails that the head constituent imposes its slot structure on the output. This means that, in compounding, only semantic information from the non-head percolates to the branching node, because only that type of information can be compatible with the semantic information of the head. All other blocks of the non-head as well as its slot structure are discarded. Note that the PROPER FUNCTION (PF) from Toquero-Pérez (2020) and the other basic functions occupy slots, as seen in the diagrams below.

The diagrams show how the SSM enables a determination of headedness in a systematic way based on the information in the slot structure of the components, along with percolation. As noted in § 2, given that the head is the constituent whose entire slot structure percolates, it follows that the head is the component that receives information from the other constituent, to form the compound as a whole. Thus, headedness in SSM is established by determining what constituent has contributed the most slots and features to a compound, which in turn enables an objective determination of what compounds are left- or right-headed in any language. In a sense, the head is the repository of the information for the entire compound, which is a new way of viewing headship. It is novel because, even though definitions of headedness have been proposed that see the head as containing key information for the entire compound, none of them view the head as a repository. For example, for Bauer (2014), the head is the constituent that defines the compound and is the superordinate term for the compound as a whole (e.g., *board* is the superordinate in *white board*). And Sun & Baayen (2021) hold that the head is the constituent from which the entire compound acquires most of its semantic and syntactic information. While this latter definition is compatible with features percolating from the head, as in SSM, it does not view the head as a repository of information.

In the generative schemata of Jackendoff (2010) we see functions embedded in other functions. It is shown below that these functions are easier to interpret if they are embedded inside lexical entries. Recall that functions are embedded even in simplex lexical items. For example, just as in *steamboat* the steam causes the boat to move, in a rocket it is (liquid) fuel that causes it to move. In compounding in SSM, the generativity comes from functions and semantic components in the lexical entries of the constituents that interact with pragmatics, and that compose with each other inside the entries, not detached from them.

The generativity of compounds is enabled not just by the combination of functions, but also by the use of additional functions. There are cases where the basic functions proposed by Jackendoff are not the only ones that can be used. For example, the LOC function is used for *inkpad* and *garlic bread*, but the "with" in the paraphrase for that type of compounds, 'N_2 with N_1 at/in/on it,' gives us a hint that the function CONTAIN (rather than LOC) can be used, giving us 'pad that contains ink' and 'bread that contains garlic'. For another example, in German *Himmelsbrot* (lit. 'heaven's bread') 'manna,' which can be translated as 'bread from heaven,' the basic function ORIGIN could be posited ('N_1 is the origin of N_2'). For another example, the meaning of *steamboat* can be paraphrased as 'a boat that moves by steam causing its movement,' with CAUSE as one of the functions. However, there are alternative paraphrases, which reflect different ways of interpreting the compound. We can say that a steamboat is 'a boat powered by steam.' In this case, the function POWER can be used to characterize that meaning.

As noted in the Introduction, a table appears in the Appendix with a list of compounds that are either illustrated in the diagrams below or mentioned as examples in relation to these diagrams. The compounds appear in the table with their token frequencies in the corpus for their respective language. These compounds have a wide range of frequencies (from 8 to 2,657 tokens for the Spanish examples) and the SSM mechanism accounts for compounds in all these frequencies. This is empirical evidence that the SSM mechanism is applicable to both frequent compounds as well as compounds which have a very low frequency; even a frequency of one, as noted in § 2.

It is also important to note that the present paper is quite similar to Jackendoff (2010) and its variants, Jackendoff (2009; 2016), in that, just as Jackendoff adapts his notation based on Conceptual Structure to account for the semantics of compounding, the current paper adapts SSM for the same purpose. The same holds for Toquero-Pérez (2020) and Schlücker (2016), both of whom adapt Jackendoff's (2010) Conceptual Semantics/Parallel Architecture model of compounding to explain aspects of the semantics of compounds in Spanish and German, respectively. In all these cases, there is an application of preexisting machinery to the domain of compounding. Thus, to the extent that these papers make any empirical generalizations, the current paper also does, on the basis of the SSM machinery.

4.1.1 NN compounds

Consider first the compound *plastic bag*. As seen in the first diagram, **Figure 3**, the slot structure of the head, *bag*, percolates via Head Percolation and semantic information from *plastic* percolates via Secondary Percolation. In contrast to the trees for derivational morphology, and for ease of interpretation, whenever an arrow is shown, indicating percolation of a feature to the head, that arrow and the percolated feature are copied into the slot structure of the head (e.g. PLASTIC in **Figure 3**). The lexical entry for the resulting compound is shown in (8). The same interpretation should be given to the remaining diagrams. Note that the COMP function in the entry for *bag* could be replaced with the Generative Lexicon feature CONSTITUTIVE.

In all the diagrams below, the entire content of the head is boldfaced so as to mark it as the head. This visual cue is especially helpful for left-headed compounds (in Spanish). Also, unlike the entries for derivation shown above, the slots are not numbered.

plastic	bag
CATEGORIAL [THING] N	**CATEGORIAL** **[THING]** **N**
	CORE **ARTIFACT** **BAG**
	PF **HOLD CONTENT**
CORE MATERIAL PLASTIC →	**COMP** **→ PLASTIC**

Figure 3: formation of *plastic bag*.

As noted above, only semantic information from the non-head percolates to the new entry (8). Thus, the diagrams show the history of the formation of the compound, and the lexical entry of the compound shows the final result. The compound *plastic bag* is now a single unit, with a corresponding single entry, just like simplex words. Recall that the entry for the compound contains features and functions also contained in simplex words. For example, because bread is made of flour, the lexical entry for *bread* should have a COMP slot with the semantic feature *flour*, and because bullets are made of metal, the lexical entry for *bullet* should contain a COMP slot with the feature *metal* (or, more specifically, *lead*). Interestingly, if there were, say, a toy bullet made of plastic, in *plastic bullet* the feature *plastic* would percolate to the entry for *bullet*, replacing *metal* in the COMP slot.

Note that a list of semantic features would not work in compounds such as this one. As shown in § 3, arranging features in a lexical entry in the form of a slot structure, rather than just listing the features, allows for predictions to be made about the behavior of groups of features during and after derivation. A mere list of features does not have the necessary internal structure to be able to account for the operations that take place during compound formation.

(8) Lexical entry for *plastic bag*

plastic bag
1 CATEGORIAL [THING] N
CORE ARTIFACT BAG
PF HOLD CONTENT
COMP PLASTIC

Note as well that although the PF and COMP slots are shown as separate from the CORE slot in **Figure 3** and in (8) (for ease of exposition), they form part of the core meaning of the compound, and thus they can percolate with the CORE slot as a single unit to form another compound, such as *plastic bag inventory*. This holds as well for the rest of the basic functions.

Regarding processing, the formation of compounds in the SSM model as represented in this section should be the same for both production and comprehension (or word recognition). In production, the speaker has the compound constituents in mind (say, *plastic* and *bag*) and unifies the entries, as in **Figure 3**. In comprehension, the individual hears the compound constituents, retrieves the entries from the mental lexicon, and unifies them. Production takes longer (Schiller & Verdonschot 2019; Archibald & Libben 2019) because there is a search for the items that will express the intended meaning (conceptual preparation), and the speaker also needs to program the vocal apparatus to produce speech. In contrast, in comprehension, which is more automatic (Archibald & Libben 2019), the individual hears the words and initiates look up of the lexical entries right away, sometimes even before the speaker has finished pronouncing the words (Pinker 1999). This process of decomposition and recomposition occurs both in compounds (Brooks & Cid de Garcia 2015) and derived words (cf. Stockall et al. 2019).

Figure 4 justifies proposing the basic function CONTENT to replace some of the LOC functions. The basic function CONTENT (in *bag*) is a part of PF and thus also of the CORE slot.

ice	bag
CATEGORIAL [THING] N	**CATEGORIAL** **[THING]** **N**
	CORE **ARTIFACT** **BAG**
	PF **HOLD CONTENT**
CORE MATERIAL ICE →	**CONTENT** **→ ICE**

Figure 4: formation of *ice bag*.

Figure 5 shows the formation of Sp. *hombre araña* ‘spider man’.

hombre ‘man’	araña ‘spider’
CATEGORIAL **[THING]** **N**	CATEGORIAL [THING] N
CORE **MAN**	
SIMILAR **SPIDER** ←	CORE SPIDER ←

Figure 5: formation of *hombre araña* ‘spider man’.

In **Figure 6**, the ARGUMENT I and ARGUMENT II of the non-head are discarded because there are no available slots.

attack	helicopter
CATEGORIAL [ACTION] N	**CATEGORIAL** **[THING]** **N**
ARGUMENT I	**CORE** **ARTIFACT** **HELICOPTER**
CORE ATTACK →	**PF** → **ATTACK**
ARGUMENT II	

Figure 6: formation of *attack helicopter*.

Figure 7 shows a compound that participates in the ARGUMENT function (implemented by the argument schema in Jackendoff 2010), in which the core information of the non-head (in this case *helicopter*) becomes an argument of the head.

helicopter	attack
CATEGORIAL [THING] N	**CATEGORIAL** **[ACTION]** **N**
CORE ARTIFACT HELICOPTER →	**ARGUMENT I** **→ HELICOPTER**
	CORE **ATTACK**
	ARGUMENT II

Figure 7: formation of *helicopter attack*.

Figure 8 shows a synthetic compound and explains why *truck driver* does not allow an object; the ARGUMENT II position is already taken by *truck*. It is a matter of filling empty slots.

truck	driver
CATEGORIAL [THING] N	**CATEGORIAL** **[THING]** **N**
	CORE **DRIVE-PERSON**
CORE ARTIFACT TRUCK →	**ARGUMENT II** → TRUCK

Figure 8: formation of *truck driver*.

Consider the possibilities for other NN compounds (diagrams are not provided due to space limitations). In *electric car*, for example, the qualia slot for *fuel* of *car* is filled with *electric*, and for *toy car*, the slot for *purpose* in *car* is filled with *play* (for *toy*). In Spanish, in *submarino nuclear* 'nuclear submarine' and *submarino espía* 'spy submarine' (both left-headed), the relevant qualia are *fuel* and *purpose*, respectively, and for the left-headed *guerra relámpago* 'lightning war' and *guerra atómica* 'atomic war,' the relevant qualia would be *manner* and, say, *means* or *weapons*, respectively.

4.1.2 AN and NA compounds

Finally, **Figure 9** shows the formation of S*chnellrestaurant* 'fast restaurant' (Schlücker 2016). Note that the Modifiee of the non-head cannot percolate because there are no slots available.

Recall that, as mentioned above, it can be said that the basic functions are integrated into the lexical entries of the constituents, and features in slot structure compose with each other. For example, in the German compound *Schnellrestaurant* (lit. 'fast restaurant,' i.e. convenience restaurant) (see Schlücker 2016), seen in **Figure 9**, the semantics of the non-head, *schnell*, is placed into the slot structure of *Restaurant*, the head, by Secondary Percolation, and the rest of the content of the schema is already a part of the entry for *Restaurant*. (This is applicable to all compounds.) In this sense, SSM is more compatible with the view in Generative Lexicon theory, where the semantics of the non-head ends up integrated in the lexical entry of the head. (However, this process is not shown in the Generative Lexicon literature, e.g. Pustejovsky 1995 or Pustejovsky & Ježek 2016.)

schnell 'fast'	Restaurant
CATEGORIAL [PROPERTY] A	**CATEGORIAL** **[THING]** **N**
	CORE **PLACE** **RESTAURANT**
	PF **SERVE FOOD**
CORE FAST →	**MANNER** → **FAST**
MODIFIEE	

Figure 9: formation of *schnell Restaurant* 'fast Restaurant'.

Other AN compounds are *postal order*, *nervous system*, Sp. *altoparlante* [high + speaker] ‘loudspeaker,’ and *bajorrelieve* [low + relief] ‘bas-relief’. NA compounds include *water soluble*, *disease inhibitory*, *world weary*, and Sp. *huelga patronal* [strike + employer-related] ‘lockout.’

4.1.3 AA and VN Compounds and Multiword Formations

AA compounds include *dark-blue*, *icy cold* and *red-hot*, and examples of VN compounds are *jump rope*, *rattlesnake* and *swearword*. Due to space limitations, sample diagrams for these types of compounds are not provided. The SSM also accounts for multiword formations (or expressions), including multiple-word compounds (e.g. *plastic bag inventory*), prepositional link compounds (e.g. *casa de campo* ‘country house’), and dual-headed compounds (e.g. *boy king*). These are analyzed in the next sub-sections.

4.1.3.1 Multiple-word compounds

A diagram for multiple-word compounds (such as *ice cream cone* and *foreign exchange flow*) is shown below. The entry for *plastic bag* in (8) is repeated below inside **Figure 10** as the left-hand constituent of the compound *plastic bag inventory*. As noted above, the PF and COMP slots form part of the core meaning of the compound, and thus they can percolate with the CORE slot as a single unit, as seen in the diagram below (note there is only one arrow in the ARGUMENT slot of *inventory*). They have been placed in separate slots for ease of exposition.

plastic bag	inventory
CATEGORIAL [THING] N	**CATEGORIAL** **[COLLECTIVE]** **N**
CORE ARTIFACT → BAG	**CORE** **GOODS/ITEMS**
PF HOLD CONTENT →	**PF** **USE-SALE**
COMP PLASTIC →	**ARGUMENT** **→ CORE, PF, COMP (of plastic bag)**

Figure 10: formation of *plastic bag inventory*.

4.1.3.2 Prepositional link compounds

Prepositional link compounds, also known as prepositional link syntagms (Lang 2013) or N Prep N constructions, are relatively frequent and productive left-headed structures where two nouns are joined by a preposition (Sp. *casa de campo* [house of countryside] ‘country house’). They are compound-like in that they are subject to the criterion of separability. That is, like compounds, they do not allow intervening material between components (e.g. **casa de maravilloso campo* [house of marvelous countryside]).

Toquero-Pérez (2020) applied the Conceptual Semantics model of compounding to the semantic interpretation of N Prep N constructions and found that many of the basic functions applied to them, showing a wider range of semantic relations as opposed to NNs (in Spanish). This prompted Toquero-Pérez (2020) to suggest that N Prep N constructions should be treated as NN compounds semantically, because their meaning can be accounted for in the same way. This in turn supports the claim by Nicoladis (2002) that in Romance languages prepositions in N Prep N constructions are becoming linking elements and are not true prepositions. That is, prepositions in these constructions are devoid of meaning. This can be seen in pairs or sets of constructions where the same preposition is used but where the constructions have unrelated meanings. For example, in *banco **de** datos* [bank of data] 'data bank,' the semantic function seems to be CONTAIN, while for *botas **de** lluvia* [boots of rain] 'rain boots,' it seems to be PURPOSE. And while in *camisa **a** cuadros* [shirt at/to squares] 'checkered shirt' the relevant function seems to be HAVE, for *lancha **a** motor* [boat at/to engine] 'motorboat' it seems to be POWERED BY, CAUSE, or something to that effect. The fact that N Prep N constructions in Spanish are usually translated into English as NN compounds (Lang 2013) tends to strengthen their status as such.

The lack of meaning of the preposition in the N Prep N construction is assumed in the current study. Thus, under an SSM analysis, only the nouns in the N Prep N construction contain a slot structure, and unification and percolation operate as in compounds, as seen in **Figure 11**, which shows the formation of *casa de campo*.

casa 'house'	de 'of' campo 'countryside'
CATEGORIAL **[THING]** **N**	1 CATEGORIAL [PLACE] N
CORE **BUILDING** **HOUSE**	
LOCATION **COUNTRYSIDE ←**	CORE COUNTRYSIDE ←

Figure 11: formation of *casa de campo* 'country house'.

A similar analysis applies for multiword expressions with more than two words (Cabezas-García & Faber 2017) (also known as multiword terms), such as *cable de alta tensión* 'high-voltage cable.' In this type of formations there can be alternative bracketings, and the linking preposition is key to determine the bracketing. Once the head has been identified (*cable*), precisely because the preposition links two elements, the elements that go after a preposition (*alta tensión*) belong in a separate grouping from the ones before the preposition, resulting in the following bracketing: [cable [de [alta tension]]]. Thus, there will be an entry for *cable* and another one for *alta tensión*, and because *cable* is the head, the meaning of the second component will fit into the entry for *cable*. For a more complex example, in *escuela para niños con necesidades especiales* 'special-needs school' (or 'school for children with special needs'), as expected, the prepositions serve to establish the dividing lines in the bracketing, which is as follows: [escuela [para [niños [con [necesidades especiales]]]]].

4.1.3.3 Dual-headed compounds

Dual-headed or *dvandva* compounds (*boy king*, *tractor trailer*), also known as juxtapositions or binominals (Lang 2013) or labeled as coordinative, copulative, or appositive (Scalise and Bisetto 2009), are interesting because many of them, in both English and Spanish, disallow a reversal of the order of their constituents, something that should not occur, because none of them is the head. For instance, while one can say *boy king*, ?*king boy* sounds strange. A search was done on the iWeb corpus (Davies 2018), and while 744 examples of *boy king* were found, no examples were found of *king boy* as a compound (only as a proper name). The same holds for, say, Sp. *mueble bar* 'bar cabinet,' where 43 instances were found in the CDE, but none for ?*bar mueble*. Other examples are *woman doctor* (?*doctor woman*), *child prodigy* (?*prodigy child*), and Sp. *café teatro* [cafe + theater] (?*teatro café*). It may be that the reversal sounds jarring because these are conventionalized forms and we are used to hearing the elements in this order.

However, it would be interesting to determine if there is an explanation on the basis of semantic functions or the compounds' lexical entries. For example, Jackendoff's (2010) BE function, say, for *boy king* ([Y_2; [Y_2 BE X_1], 'N_2 that is (also) an N_1'; 'king that is (also) a boy'), does not help to explain why ?*king boy*, as well as the other examples given above, are (presumably) disallowed. After all, the paraphrases 'boy that is a king' (for ?king boy) and '*teatro que es un café'* 'theater that is a cafe' (for ?teatro café) sound perfectly acceptable. The function BOTH from Jackendoff (2009) (BOTH (X_1,Y_2), 'both N_1 and N_2') does not help either. Just as a *boy king* is 'both a boy and a king,' a ?king boy would be 'both a king and a boy.' They have exactly the same meaning, yet the latter order is not acceptable.

A plausible explanation emerges if we take into account unification, slot structure and percolation. It may be that speakers pick one of the components as more head-like, perhaps influenced by the dominant headedness in their native language (right-headedness for English, left-headedness for Spanish). The entire slot structure of that element percolates to the branching node via Head Percolation, and this is what explains the irreversibility in the order. Because in the minds of speakers the entire slot structure of the noun selected is acting like that of a head, it feels strange to allow the other noun, whose slot structure percolates via Secondary Percolation, to now act as the head.

Note in **Figure 12** that the function ALSO is suggested as a feature to label a slot because it is part of the paraphrase for Jackendoff's (2010) schema for BE.

boy	king
CATEGORIAL [THING] N	**CATEGORIAL** **[THING]** **N**
	CORE **KING**
CORE BOY →	**ALSO** **→ BOY**

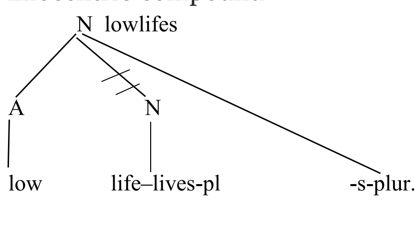
Figure 12: formation of *boy king*.

Note that it is not enough to say that speakers simply pick the noun that is in the prototypical head position and just stick with that order, and that slot structure has nothing to do with it. If speakers, say, try the order *king boy*, they can see that *boy*, now in the typical head position, could be interpreted as the more head-like noun. However, if the entire slot structure of *king* percolates, it serves as an anchor and a location where the basic functions can find a place. This view reinforces the idea, discussed in § 5, that functions are actually instantiated or embodied in slot structure, not detached from it. And in the case of the functions BE and BOTH, they need to be embedded as well (in this case, like ALSO), because on their own, in a schema, they do not seem to be able to explain the apparent irreversibility of dual-headed compounds.

4.1.4 Exocentric compounds

Finally, because the SSM crucially relies on the notion of head, the question may arise as to how the model deals with exocentric compounds, which by definition are headless. There are two explanations that account for exocentric compounds that are relevant for an SSM analysis. First, Pinker (1999) and Pinker & Ullman (2002) provide an explanation in terms of both the semantics of exocentric compounds and the way they are inflected, making reference to percolation. For example, when the noun *life* combines with *low* to form the exocentric compound *lowlife*, the compound no longer has access to the information of its constituent words, including the plural form associated with *life*. Due to pragmatics, context, and a metonymic interpretation, a *lowlife* refers to a kind of person (who leads a low life), not to a kind of life. For it to have this meaning, the percolation channel is plugged up, as seen in (9). With the pipeline to memory disabled, the slot structure of the head is not available for percolation, so no information stored with *life* (e.g. its irregular plural, *lives*) can percolate to the branching node. With the irregular plural unavailable, the default, regular *-s* is attached and we get *lowlifes* (cf. **low-lives*).

(9) Exocentric compound



All exocentric compounds work this way. For example, a *cutthroat* is not a kind of throat, a *lazybones* is not a kind of bones, and a *swansong* is not a kind of *song*. Likewise, in Spanish, a *puntapie* [tip + foot] 'kick' is not a kind of foot, a *lengualarga* (or *lengüilargo*) [tongue + long] 'person who tells on others' is neither a kind of tongue nor something long, and a *tocadiscos* [play + records] 'record player' is a device, not a kind of record. Notice the clear role played by pragmatics in the Spanish exocentric compound *lavaplatos* [wash + dishes], which can either mean 'dishwashing machine' or refer to a person who washes dishes (a dishwasher), depending on the context. For either meaning, however, the clogging of the percolation pipeline has to occur, because *lavaplatos* is definitely not a kind of dish.

The second account of exocentric compounds is Jackendoff's (2009), which is naturally based on schemas rather than on percolation. Exocentric compounds result from a schema based on metonymy and metaphor, as shown in (10), where N_1 and N_2 are both arguments of a modifying function *F*. (11) illustrates how the schema is filled out.

(10) *Exocentric compound schema*:
$[N_1\ N_2] = [Z; [F(\ldots, X_1, \ldots, Y_2, \ldots)]]$
'something such that F is true of N_1 and N_2'

(11) $\text{bird}_1\text{brain}_2 = \text{PERSON}\alpha$; [SIMILAR ($\text{BRAIN}_2\beta$ (α), Fβ (BIRD_1)]
'person whose brain is similar to that of a bird'

Because these are exocentric compounds, in both accounts, the head has to be lexically stipulated based on pragmatics. This is the case because the head cannot be determined based either on the meaning or the implied arguments of the constituents alone. For example, while *lavaplatos* 'dishwasher' can be both a person and a machine, *sacacorchos* 'corkscrew' and *tocadiscos* 'record player' can only refer to tools or devices, not to the people who handle them. Likewise, while *bird brain* and *lowlife* can only refer to people, *hammerhead* and *red-chest* can only denote kinds of animals. Thus, it could be said that pragmatics overrides the operation of percolation in this type of compounds.

5 Conclusion

This paper has shown that an analysis of compounding that employs the SSM framework brings about several important advantages. First, it has the ability to explain the generativity of compounds on the basis of the actual and potential information contained in the lexical entries of the components; it demonstrates a more systematic way to determine the headedness of a compound, regardless of the language; and it enables the simplification of the interpretation of compounds, not only of the notation, but also of the structure inside lexical entries involved in determining compound meaning. This is possible because the information related to the basic semantic functions is shown in the context of the rest of the semantic information of the lexical entries of the constituents. Jackendoff (2009; 2010; 2016) states that unexpressed semantic material (such as basic functions) is needed in order to connect the constituents of a compound. This is the case in that model because the schemas are detached from the actual lexical entries of the constituents. In contrast, in SSM the connective semantic material is expressed in the lexical entries of the components that undergo unification.

Importantly, all this is accomplished with the same machinery that is already used for derivation. The key innovation of the model is the enrichment of lexical entries through the incorporation of slots for qualia and other features, to produce a flexible, generative mechanism that accounts for the semantics of a wide range of compounds. The generativity comes from the information inside the lexical entries of the components, which interact with pragmatics, and that compose with each other inside the entries.

The enrichment of the lexical entries of the constituents in a compound can lead to a rethinking of the lexical entries of derivational affixes. For example, it may be that affixes need to have additional slots for some of the basic functions, some of which may be determined by pragmatics or world knowledge. For instance, the suffix *-ería*, which expresses Location, can have a *Purpose* slot, which in *joyería* 'jewelry store' would be filled in with the purpose *Sell* and in *enfermería* 'infirmary' with the purpose *Cure*. In English, the suffix *-ish*, which contributes the meaning of Similarity (or LIKE), could have an additional slot for Manner. When forming *piggish*, the Manner slot can be filled with a feature such as Sloppy or Dirty (from *pig*), and in *childish*, it could be filled with Silly or Immature, depending on the context.

Given that the SSM accounts for the morphology of several languages genetically unrelated to Spanish, which suggests that its constructs may be universal (§ 3), an important aspect to consider is the possible universality of the SSM approach as applied to compounding, given that it applies to such a wide range of compound types, including dual-headed compounds, prepositional link compounds, and multiword compounds. Future studies could explore the extent to which the SSM formalism applies to additional types of compounds, as well as compounds in languages unrelated to Spanish, English, and German. Japanese, for example, has endocentric NN and AN compounds that seem to be amenable to the SSM analysis (e.g. *hude-bako* 'pencil box' and *naga-banasi* 'long talk') (Kageyama & Saito 2016).

Finally, the analysis of compounds based on SSM provides further support for the notion that affixes are lexical items with structured lexical entries. The constituents of compounds are unquestionably lexical items, and affixes behave exactly like these compound constituents during word formation. If affixes were mere cues, exponents or phonological markers, as held by realizational approaches (such as those based on lexical rules or paradigms), what would explain such a similar behavior between words (in compounds) and affixes? Furthermore, the strong similarity between compounding and derivational affixation in SSM is evidence against Jackendoff's (2002; 2009; 2010; 2016) hypothesis that compounding operates under *sui generis* protogrammatical principles. Compounding seems to be just another form of derivation.

Appendix

Table 2 contains a list of compounds (in alphabetical order) that are either illustrated in the diagrams in § 4 or mentioned as examples in relation to those diagrams. The compounds appear in the table with their token frequencies in the corpus for their respective language (Corpus del Español, Web/Dialects section; iWeb corpus) or source article.

	Compound	**Corpus del Español (CDE)**	**iWeb**	**Article**
1.	altoparlante ‘loudspeaker’	229		
2.	attack helicopter		1,291	
3.	bajorrelieve ‘bas-relief’	203		
4.	banco de datos ‘data bank’	1,237		
5.	bird brain		273	
6.	botas de lluvia ‘rain boots’	64		
7.	boy king		743	
8.	cable de alta tension ‘high-voltage cable’	89		
9.	camisa a cuadros ‘checkered shirt’	222		
10.	casa de campo ‘country house’	2,657		
11.	cutthroat		8,119	
12.	dark-blue		707	
13.	disease inhibitory		1 (NOW corpus)	
14.	electric car		15,726	
15.	foreign exchange flow		2	
16.	guerra atómica ‘atomic war’	169		
17.	guerra relámpago ‘lightning war’	137		

(Contd.)

	Compound	Corpus del Español (CDE)	iWeb	Article
18.	hammerhead		5,588	
19.	helicopter attack		199	
20.	hombre araña ‘spider man’	1,080		
21.	huelga patronal ‘lockout’	8		
22.	ice bag		467	
23.	ice cream cone		4,114	
24.	icy cold		2,364	
25.	jump rope		6,226	
26.	lancha a motor ‘motorboat’	38		
27.	lavaplatos‘dishwashing machine’/‘dishwasher’	814		
28.	lazybones		262	
29.	lengualarga ‘person who tells on others’	11		
30.	lowlife		1,544	
31.	lowlifes		679	
32.	nervous system		94,056	
33.	plastic bag		31,674	
34.	plastic bag inventory		0	
35.	plastic bullet		109	
36.	postal order		1,123	
37.	puntapié ‘kick’	1,319		
38.	rattlesnake		9,604	
39.	red-chest		1	
40.	red-hot		7,980	

(Contd.)

	Compound	Corpus del Español (CDE)	iWeb	Article
41.	sacacorchos ‘corkscrew’	337		
42.	schnell Restaurant ‘convenience restaurant’			Schlücker (2016)
43.	submarino espía ‘spy submarine’	15 (NOW section)		
44.	submarino nuclear ‘nuclear sub-marine’	264		
45.	swansong		1,254	
46.	swearword		1,361	
47.	tocadiscos ‘record player’	886		
48.	tractor trailer		3,075	
49.	truck driver		16,569	
50.	water soluble		9,235	
51.	world weary		225	

Table 2: Compounds and their corpus frequency.

Competing interests

The author has no competing interests to declare.

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