HPSG – A Synopsis

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Abstract

Head-Driven Phrase Structure Grammar (HPSG) is a linguistic theory that wants to be psycholinguistically plausible and compatible with language acquisition facts. It is a model-theoretic approach and hence constraint-based. Constraints are formulated as feature value pairs, identity statements (structure sahring) and relational constraints that relate several values. HPSG *employs types that are organized in inheritance hierarchies, which makes it possible to capture both lexical and syntactic generalizations. HPSG includes all linguistic levels of description, but this article focuses on syntax and semantics. It describes how valence information is represented, how it is linked to semantic information, how certain constituent structures are licenced and how non-local dependencies can be analyzed. HPSG is a lexical theory, that is, the lexicon is a rich and structured object. Appart from the organization in inheritance hierarchies lexical rules are used to capture productive and semi-productive processes in the lexicon.*

Head-Driven Phrase Structure Grammar (HPSG) was originally developed by Ivan Sag and Carl Pollard in the mid 80s. The main publications are Pollard and Sag, 1987, 1994. International conferences have been held since 1994 and there is a rich collection of publications regarding analyses of linguistic phenomena (in the area of phonology, morphology, syntax, semantics, and information structure), formal foundations of the framework, and computational issues like efficient parsing and generation. See `http://hpsg.fu-berlin.de/HPSG-Bib/` for bibliographic data.

Since HPSG analyses are usually sufficiently formalized they can and have been implemented as computer processable grammars. This makes it possible to check the interactions of analyses with other phenomena and to use the linguistic knowledge in practical applications. See Bender et al., 2014 for further details. An overview of implementations and pointers to demos and downloadable systems can be found in Müller, 2013b, Chapter 8.

1 Formal foundations

HPSG assumes feature structures as models of linguistic objects. These feature structures are described by feature descriptions, which are also called *Attribute Value Matrix* (AVM). Such AVMs consist of feature value pairs. The values can be atomic or feature descriptions. Every feature structure is of a certain type. Types are ordered in hierarchies with the most general type at the top of the hierarchy and the most specific types at the bottom. Figure 27.1 shows an example hierarchy for the type *case* and its subtypes.

(1)

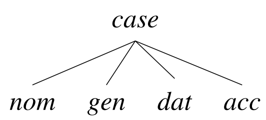


Figure 27.1: Subtypes of *case* in a grammar of German

Types in a model of a linguistic object are maximally specific, that is, a noun or an attributive adjective in a model of an actual utterance has a case value that is *nom*, *gen*, *dat*, or *acc*. The linguist develops theories that describe possible feature structures. In contrast to feature structures, feature descriptions can be partial. For instance it is not necessary to specify a case value for the German word *Frau* 'woman' since *Frau* 'woman' can be used in NPs of all four cases. (2) shows a simplified description of the nominal agreement information for the German noun *Frau* 'woman' (see Kathol, 1999 for details and Wechsler and Zlatić, 2003 for a comprehensive overview of agreement in HPSG). *Frau* 'woman' has feminine gender, is compatible with all four cases, and is singular. The AVM has the type *nom-agr*. Types are written in italics. *nom-agr* is a complex type which introduces the features GEN, CASE, and NUM. *fem*, *case*, *sg* are also types, but they are atomic. *fem* and *sg* are maximally specific, since they do not have subtypes, but *case* does have subtypes.

(2) $\begin{bmatrix} \textsc{gen} & \textit{fem} \\ \textsc{case} & \textit{case} \\ \textsc{num} & \textit{sg} \\ \textit{nom-agr} & \end{bmatrix}$

The purpose of descriptions is to constrain possible models. Since the specification of the CASE feature in (2) does not add any information, it can be omitted entirely. The AVM without the CASE feature is shown in (3):

(3) $\begin{bmatrix} \textsc{gen} & \textit{fem} \\ \textsc{num} & \textit{sg} \\ \textit{nom-agr} & \end{bmatrix}$

(2) and (3) describe the same set of feature structures.

One very important part of the formalism is structure sharing. It is used to express that information in feature structures is identical, that is, token identical rather than just type identical. Structure sharing is indicated by boxed numbers in feature descriptions. An identical number at several places in an AVM expresses the fact that the respective values are identical.

To give an example of structure sharing, the agreement information of a noun in German has to be compatible with the agreement information of the adjective and the determiner. This compatibility is established by identifying a part of the structure that represents a noun with parts of the structure for the adjective and the determiner in an NP. In an analysis of (4), the definite article has to be compatible with the description in (3).

(4) die Frau [German]
the woman
'the woman'

die 'the' is ambiguous between feminine singular nominative/accusative and plural nominative/ accusative.

(5) $\begin{bmatrix} \textsc{gen} & \textit{fem} \\ \textsc{case} & \textit{nom} \vee \textit{acc} \\ \textsc{num} & \textit{sg} \\ \textit{nom-agr} & \end{bmatrix} \vee \begin{bmatrix} \textsc{case} & \textit{nom} \vee \textit{acc} \\ \textsc{num} & \textit{pl} \\ \textit{nom-agr} & \end{bmatrix}$

Since *Frau* is singular, only feminine singular nominative/accusative is compatible with this noun. The result of identifying the feature bundles of *die* and *Frau* therefore is (6):

(6) $\begin{bmatrix} \textsc{gen} & \textit{fem} \\ \textsc{case} & \textit{nom} \vee \textit{acc} \\ \textsc{num} & \textit{sg} \\ \textit{nom-agr} & \end{bmatrix}$

While structure sharing is the most characteristic expressive means in HPSG there is one extension of the basic formalism that plays a crucial role in most HPSG analyses: relational constraints. Relational constraints are used to relate several values in a feature structure to each other. The relational constraint that is used most often in HPSG is *append* ($\oplus$). *append* is used to concatenate two lists. The schema in (14), which will be discussed in Section 2.2, is an example for an application of such a constraint.

This brief sketch mentioned many essential concepts that are used in HPSG. Of course a lot more could be and has been said about the properties of the formalisms, but this introductory article is not the place to discuss them in detail. However, it cannot be emphasized enough that it is important that the formal details are worked out and the interested reader is referred to the work of Shieber (1986), Pollard and Sag (1987, Chapter 2), Johnson (1988), Carpenter (1992), King (1994, 1999), Pollard (1999) and Richter (2004, 2007). The work of King, Pollard, and Richter reflects current assumptions, that is, the model theoretic view on grammar that is assumed nowadays.

Before I start to discuss several phenomena and their analyses in HPSG in the following sections I want to give an overview of the general feature geometry as it was developed in Pollard and Sag, 1994. (7) shows parts of the lexical item for *Mannes* 'man', the genetive form of *Mann* 'man'.

(7)
$$\begin{bmatrix} \text{PHONOLOGY} \ \langle \textit{mannes} \rangle & \\ \text{SYNTAX-SEMANTICS} & \begin{bmatrix} \text{LOCAL} & \begin{bmatrix} \text{CATEGORY} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{AGR} \ \boxed{1} \begin{bmatrix} \text{GEN} & \textit{mas} \\ \text{CASE} & \textit{gen} \\ \text{NUM} & \textit{sg} \\ \textit{nom-agr} & \end{bmatrix} \\ \textit{noun} \end{bmatrix} \\ \text{SPR} & \langle \text{DET}[\text{AGR}\ \boxed{1}] \rangle \\ \textit{category} & \end{bmatrix} \\ \text{CONTENT} & \ldots \begin{bmatrix} \text{INST} & X \\ \textit{mann} & \end{bmatrix} \\ \textit{local} & \end{bmatrix} \\ \text{NONLOCAL} \ldots & \\ \textit{synsem} & \end{bmatrix} \\ \textit{word} & \end{bmatrix}$$

The first feature value pair describes the phonological form of the word. The value of PHON is a list of phonemes. For reasons of readability usually the orthographic form is given in HPSG papers and phonological structure is omitted, but see Bird and Klein, 1994, Bird, 1995, Orgun, 1996, Höhle, 1999, Klein, 2000, and Asudeh and Klein, 2002 for analyses. The second feature is SYNTAX-SEMANTICS (SYNSEM) and its value is a description of all properties of a linguistic object that are syntactically and semantically relevant and can be selected by other heads. Information that is locally relevant (LOCAL) is distinguished from information that plays a role in non-local dependencies (NONLOCAL, see Section 4). Syntactic information is represented under CATEGORY (CAT) and semantic information under CONTENT (CONT). The example shows the HEAD value, which provides information about all aspects that are relevant for the external distribution of a maximal projection of a lexical head. In particular the part of speech information (*noun*) is represented under HEAD. The value of AGREEMENT (AGR) is parallel to the one given in (2). As well as information regarding the head features, valence information also belongs under CAT. The example shows the SPR feature, which is used for the selection of a specifier (see the next section for details on valence). The $\boxed{1}$ is an example of structure sharing. It ensures that the specifier that is realized together with the noun has compatible agreement features.

The AVM in (7) shows a description of phonological, morpho-syntactic, and semantic aspects of a word. But of course other aspects can be and have been described by feature value pairs as well. For instance Engdahl and Vallduví (1996), Kuhn (1996), Wilcock (2001), De Kuthy (2002), Paggio (2005), Bildhauer (2008), and Bildhauer and Cook (2010) show how information structure can be modeled in HPSG in general and how the interaction between phonology, syntax, and information structure can be captured in a constraint-based setting. For general discussion of interfaces between the linguistic levels of description see Kuhn, 2007.

2 Valence and constituent order

2.1 Valence

Descriptions of lexical elements contain a list with descriptions of the syntactic and semantic properties of their arguments. This list is called Argument Structure (ARG-ST). (8) gives some prototypical examples for ARG-ST values.

(8)

Verb	ARG-ST	SPR	COMPS
sleeps	⟨ NP[*nom*] ⟩	⟨ NP[*nom*] ⟩	⟨ ⟩
likes	⟨ NP[*nom*], NP[*acc*] ⟩	⟨ NP[*nom*] ⟩	⟨ NP[*acc*] ⟩
talks	⟨ NP[*nom*], PP[*about*] ⟩	⟨ NP[*nom*] ⟩	⟨ PP[*about*] ⟩
gives	⟨ NP[*nom*], NP[*acc*], NP[*acc*] ⟩	⟨ NP[*nom*] ⟩	⟨ NP[*acc*], NP[*acc*] ⟩

In (8) items like NP[*nom*] are abbreviations that stand for feature descriptions. The elements in the ARG-ST list are ordered according to the obliqueness hierarchy suggested by Keenan and Comrie (1977) and Pullum (1977).

(9) SUBJECT => DIRECT OBJECT => INDIRECT OBJECT => OBLIQUES => GENITIVES => OBJECTS OF COMPARISON

In grammars of configurational languages like English, the ARG-ST list is mapped onto two valence features: SPR (SPECIFIER) and COMPS (COMPLEMENTS). Examples for the respective values are also given in (8).

The HPSG representation of valence is reminiscent of Categorial Grammar (see Baldridge 2014 for an overview), where each head comes with a description of its arguments. Figure 27.2 shows the saturation of the subject valence: A head that requires a subject can be combined with a subject that matches the description in the SPR list. The $\boxed{1}$ indicates that the single element of the SPR list and the subject NP are identical. Therefore accusative NPs like *him* are excluded as a subject of *sleeps*.

(10)

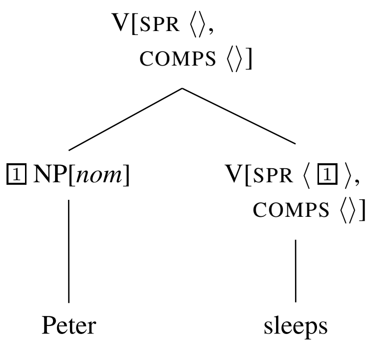


Figure 27.2: Analysis for *Peter sleeps.*

The elements in valence lists are canceled off once the combination with an appropriate item has taken place, that is the SPR list of *Peter sleeps* is empty since the SPR element of *sleeps* is realized as a sister of *sleeps*. Figure 27.3 shows a more complex example with a transitive verb.

(11)

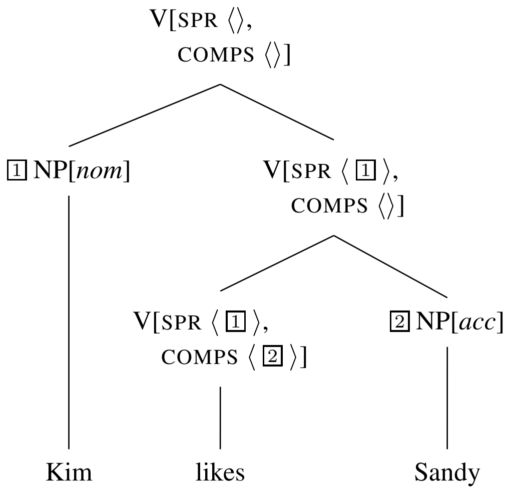


Figure 27.3: Analysis for *Kim likes Sandy.*

likes and *Sandy* form a VP (a verbal projection with an empty COMPS list) and this VP is combined with its subject to form a fully saturated verbal projection, that is, a clause.

2.2 Constituent structure

As was explained in Section 1, HPSG exclusively uses feature descriptions with structure sharing and relational constraints for describing linguistic objects. As a consequence of this, the theory does not use phrase structure rules. (Of course a phrase structure component can be used and is used in computational implementations of HPSG for efficiency reasons, but phrase structural rules are not necessary on theoretical grounds and hence are replaced by constraints which results in a leaner architecture.) Instead the dominance relation between linguistic objects is modeled with feature structures. Trees are used for visualization purposes only. The attribute value matrix that expresses the dominance relations in the tree in Figure 27.4 is shown in (13).

(12)

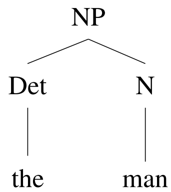


Figure 27.4: *the man*

(13)
$$\begin{bmatrix} \text{PHON} & \langle \textit{the man} \rangle \\ \text{HEAD-DTR} & \begin{bmatrix} \text{PHON} \ \langle \textit{man} \rangle \end{bmatrix} \\ \text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{PHON} \ \langle \textit{the} \rangle \end{bmatrix} \right\rangle \end{bmatrix}$$

For explanatory purposes (13) shows the phonological information only. Part of speech information and valence information that is contained in the tree in Figure 27.4 is omitted. The value of PHON is a list of phonological contributions of the daughter signs. The feature HEAD-DTR is appropriate for headed structures. Its value is the sign that contains the head of a complex expression (the verb in a VP, the VP in a clause). The value of NON-HEAD-DTRS is a list of all other daughters of a sign.

The following implication shows the constraints that hold for structures of type *head-complement-phrase*:

(14) Head-Complement Schema (fixed order, head-initial):
head-complement-phrase ⇒

$$\begin{bmatrix} \text{SYNSEM}|\text{LOC}|\text{CAT}|\text{COMPS } \boxed{1} \\ \text{HEAD-DTR}|\text{SYNSEM}|\text{LOC}|\text{CAT}|\text{COMPS } \langle \boxed{2} \rangle \oplus \boxed{1} \\ \text{NON-HEAD-DTRS } \left\langle \begin{bmatrix} \text{SYNSEM } \boxed{2} \end{bmatrix} \right\rangle \end{bmatrix}$$

This constraint splits the COMPS list of the head daughter into two parts: a list that contains exactly one element ($\langle\boxed{2}\rangle$) and a remaining list ($\boxed{1}$). The first element of the COMPS list is identified with the SYNSEM value of the non-head daughter. It is therefore ensured that the description of the properties of the complement of a transitive verb like *likes* in Figure 27.3 is identified with the feature value bundle that corresponds to the properties of the object that is combined with the head, *Sandy* in the case of Figure 27.3. Since the Head-Complement Schema in (14) licenses structures with exactly one head daughter and exactly one non-head daughter, head-complement structures will be binary. This is not the only option for defining head-complement structures. The constraints can be specified in a way that allows for the realization of any number of complements in one go. See for instance Pollard and Sag, 1994 for an analysis of English with a flat VP and Bouma and van Noord (1998) for an absolutely flat analysis of Dutch, including a flat verbal complex.

The Head-Complement Schema in (14) licences the VP in Figure 27.3. The combination of the VP and its specifier is licenced by the Head-Specifier Schema:

(15) Head-Specifier Schema:
head-specifier-phrase ⇒

$$\begin{bmatrix} \text{SYNSEM}|\text{LOC}|\text{CAT}|\text{SPR } \boxed{1} \\ \text{HEAD-DTR}|\text{SYNSEM}|\text{LOC}|\text{CAT}|\text{SPR } \boxed{1} \oplus \langle \boxed{2} \rangle \\ \text{NON-HEAD-DTRS } \left\langle \begin{bmatrix} \text{SYNSEM } \boxed{2} \end{bmatrix} \right\rangle \end{bmatrix}$$

Note that the non-head daughter is taken from the end of the SPR list, while the non-head daughter in head-complement phrases is taken from the beginning. For heads that have exactly one specifier this difference is irrelevant, but in the analysis of object shift that is suggested by Müller and Ørsnes (2013), the authors assume multiple specifiers and hence the difference in order of combination is relevant.

Note that Pollard and Sag (1994, Chapter 9) use a special valence feature for the subject and a special schema for combining subjects with their heads. As was argued convincingly by Pollard and Sag, information about subjects has to be represented in addition to the information about specifiers in order to account for predication structures, but this does not mean that a SUBJ feature has to be a valence feature. Instead I follow Pollard (1996) and Kiss (1995) and assume that SUBJ is a head feature. This change makes it possible to analyze determiner noun combinations and NP VP combinations with one schema rather than with two schemata as in earlier versions of HPSG.

2.3 Constituent order

In the simple NP example above the order of the elements is fixed: the head follows the non-head. However this is not always the case. For instance there are mixed languages like Persian that allow some heads to the left of their arguments and some heads to the right (Prepositional phrases are head-initial and verb phrases are head-final in Persian). For such reasons HPSG assumes a separation between immediate dominance (ID) constraints and linear precedence (LP) constraints as was common in GPSG (Gazdar et al., 1985). For instance, the Head-Complement Schema in (14) does not impose any order on the head and the non-head. This is taken care of by a set of separate constraints.

Heads that precede their complements can be marked as INITIAL+ and those which follow their complements as INITIAL−. The following LP constraints ensure the right ordering of heads with respect to their complements:

(16) a. HEAD [INITIAL+] < COMPLEMENT
b. COMPLEMENT < HEAD [INITIAL−]

2.4 Free constituent order languages

The Head-Complement Schema in (14) allows for the combination of a head with its complements in a fixed order, since the first element on the COMPS list is combined with the head before all other elements. (This is similar to what is known from Categorial Grammar.) Taken together with the linearization constraint in (16a), this results in a fixed constituent order in which the verb precedes its complements and the complements are serialized according to their obliqueness. However there are languages with much freer constituent order than English. If one does not want to assume a base order from which other orders are derived by movement or equivalents to movement one has to find ways to relax the constraint on head complement structures. One way of doing this is to allow the non-head daughter to be an arbitrary element from the COMPS list of the head daughter. The respective modification of the schema in (14) is given as (17):

(17) Head-Complement Schema (free constituent order):
head-complement-phrase ⇒

$$\begin{bmatrix} \text{SYNSEM}|\text{LOC}|\text{CAT}|\text{COMPS } \boxed{1} \oplus \boxed{3} \\ \text{HEAD-DTR}|\text{SYNSEM}|\text{LOC}|\text{CAT}|\text{COMPS } \boxed{1} \oplus \langle \boxed{2} \rangle \oplus \boxed{3} \\ \text{NON-HEAD-DTRS } \left\langle \begin{bmatrix} \text{SYNSEM } \boxed{2} \end{bmatrix} \right\rangle \end{bmatrix}$$

The COMPS list of the head daughter is split into three parts: a list of arbitrary length ($\boxed{1}$), a list containing one element ($\langle \boxed{2} \rangle$) and another list of arbitrary length ($\boxed{3}$). $\boxed{1}$ and $\boxed{3}$ can be the empty list or contain one or more arguments.

For non-configurational languages it is assumed that the subject of finite verbs is treated like the other arguments, that is, it is mapped to COMPS instead of being mapped to SPR as in English. Having explained the difference in the HPSG analysis of configurational and non-configurational languages we can now give an example of an analysis of a language with rather free constituent order: The Figures 27.5 and 27.6 show the analysis of the German sentences in (18):

(18) a. [weil] jeder das Buch kennt [German]
because everybody the book knows
'because everybody knows the book'
b. [weil] das Buch jeder kennt
because the book everybody knows

(19)

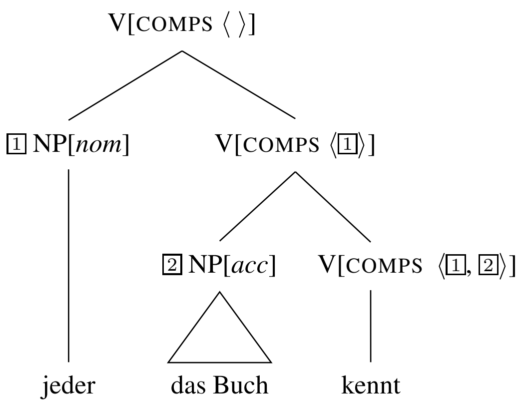


Figure 27.5: Analysis of *jeder das Buch kennt* 'everybody the book knows'

(20)

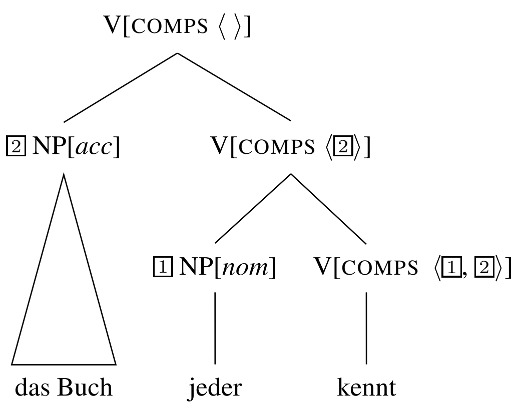


Figure 27.6: Analysis of *das Buch jeder kennt* 'the book everybody knows'

In Figure 27.5 the object is combined with the verb first and the subject is represented in the COMPS list of the mother and in Figure 27.6 the subject is combined with the verb first and the object is represented in the COMPS list of the mother. As far as constituent ordering is concerned, this analysis is equivalent to proposals that assume a set for the representation of valence information. Any element from the set can be combined with its head. Such analyses were suggested very early in the history of HPSG by Gunji (1986) for Japanese. See also Hinrichs and Nakazawa (1989), Pollard (1996), and Engelkamp, Erbach and Uszkoreit (1992) for set-based approaches to constituent order in German. A crucial difference between a set-based analysis and the list-based analysis advocated here is that the elements of the lists are ordered in order of obliqueness. This order is used in various subparts of the theory for instance for assignment of structural case and for expressing constraints on pronoun binding. So the obliqueness ordering has to be represented elsewhere in set-based approaches.

For authors who assume binary branching structures the difference between languages with fixed constituent order and languages with free constituent order lies in the value of $\boxed{1}$ and $\boxed{3}$ in the schema in (17). If either $\boxed{1}$ or $\boxed{3}$ is the empty list one gets a fixed constituent order, with head-complement combination either in order of obliqueness or in the reverse order of obliqueness.

A more radical approach to constituent order was first developed by Mike Reape (1994) for German and later adopted by other researchers for the analysis of constituent order in German (Kathol, 1995, 2000; Müller, 1995, 1999, 2002, 2004) and other languages. (Note though, that Müller, 2005a,b argued that clause structure in German should not be analyzed in a domain-based way since this approach cannot account for multiple frontings that were documented in Müller, 2003. Instead, a head-movement approach (Kiss and Wesche, 1991; Frank, 1994; Kiss, 1995; Meurers, 2000) was found more appropriate.) Another phenomenon for which these so-called linearization-based analyses seem to be needed is coordination (Crysmann, 2008; Beavers and Sag, 2004). In Reape's approach constituent structure is entirely separated from linear order. Dependents of a head are inserted into a list, the so-called order domain. Elements that are inserted into the list can be ordered in any way provided no linearization rule is violated. In such a setting the structural order in which arguments are combined with their head is kept constant but the phonological serialization differs. Figure 27.7 shows an example analysis of the sentence in (21):

(21) [dass] der Mann der Frau das Buch gibt [German]
that the man the woman the book gives
'that the man gives the book to the woman'

The arguments of *gibt* are represented in the COMPS list in the order of obliqueness (nom, acc, dat). They are combined with the verb in this order and representations for the arguments are inserted into the constituent order domain of the head (the DOM list).

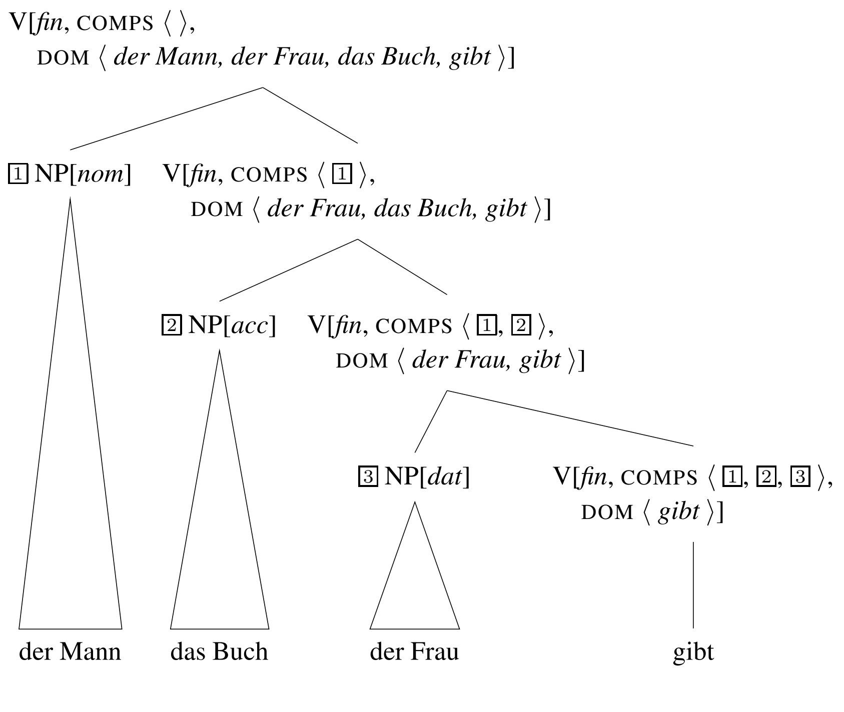
(22)


Figure 27.7: Linearization analysis of the sentence *der Mann der Frau das Buch gibt* 'the man the woman the book gives'

In the analysis of (22) this results in a discontinuous constituent for *der Frau gibt* since the dative object *der Frau* and the verb are combined first and only later is the accusative object *das Buch* inserted between *der Frau* and *gibt*.

Such domain-based analyses have been suggested for languages with even freer order. For instance Warlpiri is a language that allows attributive adjectives to be serialized independently of the noun they modify. This can be modeled by inserting the adjective independently of the noun into a serialization domain (Donohue and Sag, 1999).

While such linearization analyses are very interesting, the machinery that is required is rather powerful. Bender (2008) has shown how Wambaya – a language with similar constituent order freedom – can be analyzed in the framework of HPSG without assuming discontinuous constituents: instead of canceling the valence requirements in the way that is standard in HPSG and that was illustrated above, Bender assumes a non-cancellation approach to valence (Meurers, 1999; Przepiórkowski, 1999; Müller, 2008), that is, all the information in the ARG-ST list is projected to the highest node in the clause. By doing this, information about the syntactic and semantic properties of the arguments is available at each projection in the clause. Making the ARG-ST information avalible at higher nodes is similar to what LFG does with the f-structures: all elements in a head domain can contribute to and access the same f-structure node. Since this information is available, case agreeing attributive adjectives can be realized far away from the head they modify (see Nordlinger 1998 for an LFG analysis of Wambaya that relies on accessing f-structure information).

To sum up, there are three approaches to free constituent order: Flat structures, linearization domains with discontinuous constituents, and the non-cancellation of syntactic and semantic properties of arguments.

2.5 Heads and projection of head features

Section 1 introduced head features and Figure 27.7 shows that the information about part of speech and finiteness of the head is present at every projection, but until now nothing has been said about head feature propagation. The identity of the head features of a head and of a mother node is taken care of by the following principle:

(23) Head Feature Principle: In a headed phrase, the HEAD value of the mother and the HEAD value of the head daughter are identical.

This can be formalized by the following implicational constraint:

(24) *headed-phrase* ⇒

$$\begin{bmatrix} \text{SYNSEM}|\text{LOCAL}|\text{CAT}|\text{HEAD}\ \boxed{1} \\ \text{HEAD-DTR}|\text{SYNSEM}|\text{LOCAL}|\text{CAT}|\text{HEAD}\ \boxed{1} \end{bmatrix}$$

The head daughter is the daughter that contains the syntactic head, that is in the phrase *der Frau gibt* in Figure 27.7 it is the lexical item *gibt* and in the phrase *der Frau das Buch gibt* it is the constituent *der Frau gibt*. The constraint is a constraint on structures of type *headed-phrase*. Types like *head-complement-phrase* are subtypes of *headed-phrase* and hence the constraint in (24) applies to them too.

3 Semantics

The first publications on HPSG assumed Situation Semantics (Barwise and Perry, 1983) as the underlying semantic framework (Pollard and Sag, 1987, 1994). While there are also more recent publications in this tradition (Ginzburg and Sag, 2000), many current analyses use semantic formalisms that allow for the underspecification of scope constraints such as for instance *Underspecified Discourse Representation Theory* (UDRT, Frank and Reyle 1995), Constraint Language for Lambda Structures (CLLS, Egg et al. 2001), Minimal Recursion Semantics (MRS, Copestake, Flickinger, Pollard and Sag 2005) and Lexical Resource Semantics (LRS, Richter and Sailer 2004). Minimal Recursion Semantics is widely used in the theoretical literature and in computational implementations of HPSG grammars and is also adopted by researchers working in other frameworks (See Kallmeyer and Joshi, 2003 for an MRS semantics for TAG, Kay, 2005 for a CxG fragment with an MRS semantics and Dyvik, Meurer and Rosén, 2005 for the combination of LFG and MRS). In what follows I will briefly explain the basic assumptions of MRS and their AVM encoding.

(25) shows the examples for the semantic contribution of a noun and a verb in Minimal Recursion Semantics:

(25) a. *dog*

$$\begin{bmatrix} \text{IND} & \boxed{1}\begin{bmatrix}\text{PER} & \textit{3}\\ \text{NUM} & \textit{sg}\\ \text{GEN} & \textit{neu}\\ \textit{index} & \end{bmatrix}\\ \text{RELS} & \left\langle \begin{bmatrix}\text{INST} & \boxed{1}\\ \textit{dog} & \end{bmatrix}\right\rangle \\ \textit{mrs} & \end{bmatrix}$$

b. *chases*

$$\begin{bmatrix} \text{IND} & \boxed{1}\ \textit{event}\\ \text{RELS} & \left\langle \begin{bmatrix}\text{EVENT} & \boxed{1}\\ \text{AGENT} & \textit{index}\\ \text{PATIENT} & \textit{index}\\ \textit{chase} & \end{bmatrix}\right\rangle \\ \textit{mrs} & \end{bmatrix}$$

An MRS consists of an index, a list of relations, and a set of handle constraints, which will be introduced below. The index can be a referential index of a noun (25a) or an event variable (25b). In the examples above the lexical items contribute the *dog* relation and the *chase* relation. The relations can be modeled with feature structures by turning the semantic roles into features. The semantic index of nouns is basically a variable, but it comes with an annotation of person, number, and gender since this information is important for establishing correct pronoun bindings.

The arguments of each semantic relation (e.g. agent, patient) are linked to their syntactic realization (e.g. NP[nom], NP[acc]) in the lexicon. (26) shows an example. NP[nom]$_{\boxed{1}}$ stands for a description of an NP with the semantic index identified with $\boxed{1}$. The semantic indices of the arguments are structure shared with the arguments of the semantic relation *chase*′.

(26) *chase*:

$$\begin{bmatrix} \text{CAT} & \begin{bmatrix}\text{HEAD} & \begin{bmatrix}\text{VFORM} & \textit{fin}\\ \textit{verb} & \end{bmatrix}\\ \text{ARG-ST} & \left\langle \text{NP}[\textit{nom}]_{\boxed{1}}, \text{NP}[\textit{acc}]_{\boxed{2}} \right\rangle \end{bmatrix}\\ \text{CONT} & \begin{bmatrix}\text{IND} & \boxed{3}\ \textit{event}\\ \text{RELS} & \left\langle \begin{bmatrix}\text{EVENT} & \boxed{3}\\ \text{AGENT} & \boxed{1}\\ \text{PATIENT} & \boxed{2}\\ \textit{chase} & \end{bmatrix}\right\rangle \\ \textit{mrs} & \end{bmatrix} \end{bmatrix}$$

Generalizations over linking patterns can be captured elegantly in inheritance hierarchies (see Section 7 on inheritance hierarchies and Wechsler 1995; Davis 2001; Davis and Koenig 2000 for further details on linking in HPSG).

(27)

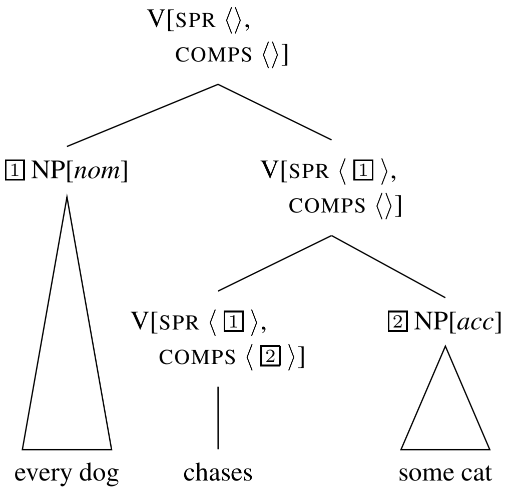


Figure 27.8: Analysis for *Every dog chases some cat.*

Before turning to the compositional analysis of (28a), I want to introduce some additional machinery that is needed for the underspecified representation of the two readings in (28b,c).

(28) a. Every dog chased some cat.
b. $\forall x(dog(x) \rightarrow \exists y(cat(y) \wedge chase(x, y)))$
c. $\exists y(cat(y) \wedge \forall x(dog(x) \rightarrow chase(x, y)))$

Minimal Recursion Semantics assumes that every elementary predication comes with a label. Quantifiers are represented as three-place relations that relate a variable and two so-called handles. The handles point to the restriction and the body of the quantifier, that is, to two labels of other relations. (29) shows a (simplified) MRS representation for (28a).

(29) ⟨ h0, { h1: every(x, h2, h3), h2: dog(x), h4: chase(e, x, y),
h5: some(y, h6, h7), h6: cat(y) } ⟩

The three-place representation of quantifiers is a syntactic convention. Formulae like those in (28) are equivalent to the results of the scope resolution process that is described below.

The MRS in (29) can best be depicted as in Figure 27.9. h0 stands for the top element. This is a handle that dominates all other handles in a dominance graph. The restriction of *every* points to *dog* and the restriction of *some* points to *cat*. The interesting thing is that the body of *every* and *some* is not fixed in (29). This is indicated by the dashed lines in Figure 27.9 in contrast to the straight lines connecting the restrictions of the quantifiers with elementary predications for *dog* and *cat*, respectively.

(30)

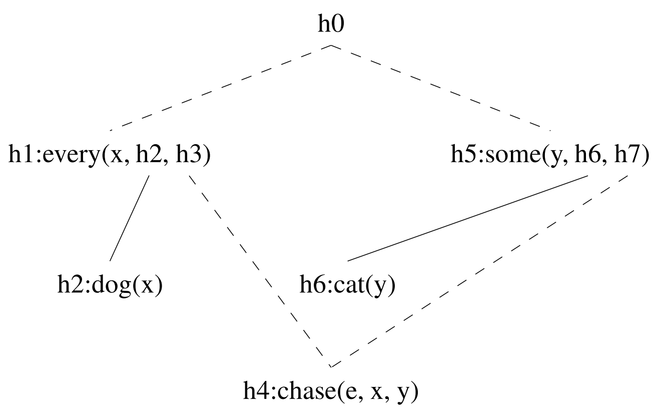


Figure 27.9: Dominance graph for *Every dog chases some cat.*

There are two ways to plug an elementary predication into the open slots of the quantifiers:

(31) a. Solution one: h0 = h1 and h3 = h5 and h7 = h4.
(*every dog* has wide scope)

b. Solution two: h0 = h5 and h7 = h1 and h3 = h4.
(*some cat* has wide scope)

The solutions are depicted as Figure 27.10 and Figure 27.11.

(32)

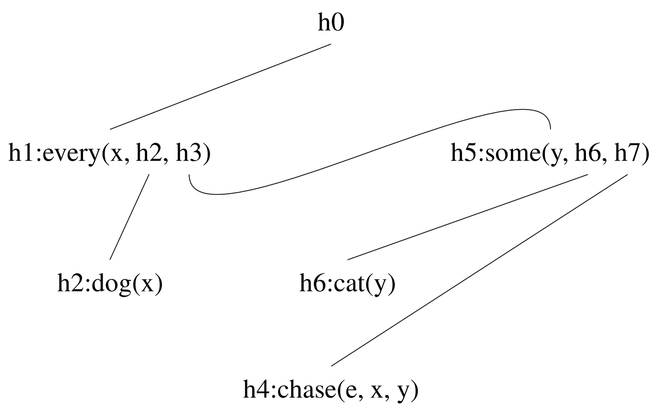


Figure 27.10: every(x, dog(x), some(y, cat(y), chase(x, y))) $\equiv$ (28b)

(33)

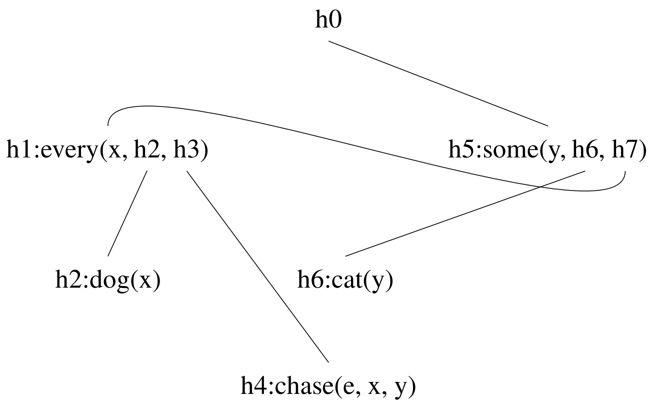


Figure 27.11: some(y, cat(y), every(x, dog(x), chase(x, y))) $\equiv$ (28c)

There are scope interactions that are more complicated than those we have been looking at so far. In order to be able to underspecify the two readings of (34) both slots of a quantifier have to stay open (Copestake et al., 2005, 296).

(34) a. *Every nephew of some famous politician runs.*

b. every(x, some(y, famous(y) $\wedge$ politician(y), nephew(x, y)), run(x))

c. some(y, famous(y) $\wedge$ politician(y), every(x, nephew(x, y), run(x)))

In the analysis of example (28a), the handle of *dog*′ was identified with the restriction of the quantifier *every*′. This would not work for (34a) since either *some*′(...) or *nephew*′(x, y) can be the restriction of *every*′. Instead of direct specification so-called handle constraints are used (*qeq* or $=_q$). A qeq constraint relates an argument handle and a label: h $=_q$ l means that the handle is identified with the label directly or one or more quantifiers are inserted between *h* and *l*. Taking this into account, we can now return to our original example. The correct MRS representation of (28a) is given in (35).

(35) $\langle$ h0, { h1:every(x, h2, h3), h4:dog(x), h5:chase(e, x, y),
h6:some(y, h7, h8), h9:cat(y) }, { h2 $=_q$ h4, h7 $=_q$ h9 } $\rangle$

The handle constraints are associated with the lexical entries for the respective quantifiers. They are represented in a list as the value of a feature called HCONS. Figure 27.12 shows the analysis.

(36)

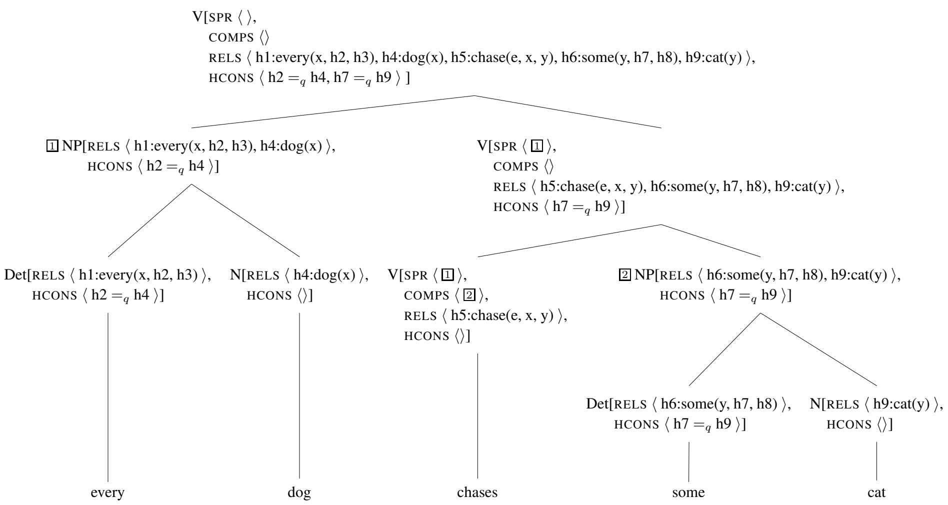


Figure 27.12: Analysis for *Every dog chases some cat.*

The RELS value of a sign is simply the concatenation of the RELS values of the daughters. Similarly the HCONS value is a concatenation of the HCONS values of the daughters. See Copestake et al., 2005 for an extension of this mechanism that allows for the inclusion of semantic information at the phrasal level.

An interesting application of the underspecification of scope constraints is the treatment of the ambiguity of (37a).

(37) a. dass Max alle Fenster aufmachte [German]
that Max all windows opened
'that Max opened all windows'

b. ∀ x (window(x) → CAUSE(max, open(x)))

c. CAUSE(max, ∀ x (window(x) → open(x)))

The first reading corresponds to a situation in which all windows were closed and Max opens each window and the second reading corresponds to a situation in which some windows were open already and Max opened the remaining windows which results in a situation in which all windows are open.

Egg (1999) suggests specifying the meaning of *öffnen* 'to open' in an underspecified way. (38) gives an MRS version of his analysis:

(38) ⟨ h0, { h1:CAUSE(x, h2), h3:open(y) }, { h2 $=_q$ h3 } ⟩

The CAUSE operator embeds the *open* 'to open' relation, but the embedding is not direct. It is stated as a dominance constraint h2 $=_q$ h3. This allows for quantifiers to scope between the CAUSE operator and the embedded predicate and therefore admits the readings in (37b,c). The analysis also extends to the readings that can be observed for sentences with adverbials like *wieder* 'again'. The sentence in (39a) has three readings that originate from different scopings of CAUSE, ∀, and *wieder* 'again':

(39) a. dass Max alle Fenster wieder aufmachte [German]
that Max all windows again opened
'that Max opened all windows again'

b. CAUSE > ∀ > *again*′ > *open*′

c. ∀ > CAUSE > *again*′ > *open*′

d. ∀ > *again*′ > CAUSE > *open*′

The first two readings are so-called repetitive readings and the third one is a restitutive reading. See Dowty, 1979, Section 5.6 on this phenomenon. Since only the relative scope of CAUSE and *open*′ is fixed in the lexical representation in (38), other scope-taking elements can intervene.

With such a semantic representation the syntax-semantics interface can be set up as follows: the adverbial combines with *aufmachen* 'to open' and the resulting phrase is combined with the object *alle Fenster* 'all windows' and the subject *Max*. The scoping of the universal quantifier and the adverbial *wieder* 'again' depends on the ordering of the elements, that is, in (39a) only readings in which ∀ outscopes *again*′ are available. See Kiss, 2001 for more information of the treatment of quantifier scope in German in the framework of HPSG.

Egg (1999) suggests the underspecification analysis as an alternative to von Stechow's analysis in the Minimalist Program (1996). Von Stechow assumes a decomposition in syntax in the style of Generative Semantics and relies on several empty heads and movement operations that are necessary to derive readings. As was pointed out by Jäger and Blutner (2003) the analysis does not get all attested readings. Apart from such empirical problems, the underspecification analysis has to be preferred for conceptual reasons: the syntactic structures directly correspond to observable facts and hence it seems more likely that a performance model can be paired with such a surface-oriented approach. Apart from this surface-oriented structures do not require a rich innate UG to explain the acquisition of language (see Section 8). See also Richter and Sailer, 2008 for arguments for a richer syntax-semantics interface as opposed to proposals that derive certain readings via syntactic movement operations.

4 Nonlocal dependencies

The basic ingredients for the analysis of nonlocal dependencies like the one in (40) are taken over from GPSG analyses (Gazdar, 1981; Gazdar, Klein, Pullum and Sag, 1985).

(40) [*People like him*]$_i$, *everybody knows I dislike* _$_i$.

In (40) the object of *dislike* is realized outside of the clause. While examples like (40) were seen as a motivation for movement transformations, Gazdar found a way to analyze such nonlocal dependencies as a series of local dependencies. The main idea is that the information about the fact that something is missing in the object position next to *dislike* is recorded locally and passed up to mother nodes that embed the VP until the phrase *people like him* is found and fills in the missing information about the object of *dislike*. (I explain the analysis in a bottom-up fashion starting with lexical items, but this is just for explanatory reasons. HPSG grammars are a collection of constraints without a specific order of application.) HPSG uses features, values, and structure sharing to establish the link between a missing element (a gap or trace) and its filler (Pollard and Sag, 1994, Chapter 5). Figure 27.13 shows the basic mechanism.

(41)

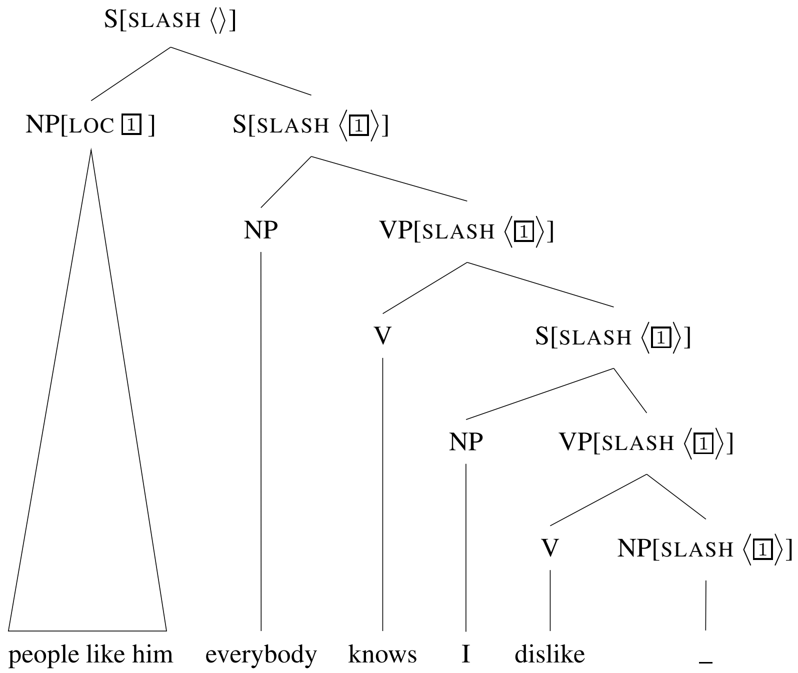


Figure 27.13: Percolation of nonlocal information

The figure shows an empty element for the introduction of the nonlocal dependency, but alternatives to trace-based approaches have been suggested. One such alternative is the assumption of additional dominance schemata that do not require certain arguments but instead introduce an element into SLASH. This is basically equivalent to the traceless meta rule approach in the framework of GPSG (Uszkoreit, 1987, 76–77). Another traceless analysis is the lexical approach of Bouma, Malouf and Sag (2001), in which only those arguments are mapped from ARG-ST to the valence features that are not extracted. The extracted arguments are mapped to SLASH instead. See Müller, 2009 on problems of this approach with raising and Levine and Hukari, 2006 for an elaborated discussion of various extraction analyses in HPSG.

In the following I want to discuss the trace-based approach in more detail. The following AVM is a description of a trace. The local properties of a linguistic object are identified with an element in a list, which is the value of the SLASH feature under the path INHERITED (INHER). (The original HPSG treatment of nonlocal dependencies assumed that the value of the SLASH feature is a set. Recent versions – for instance Müller 1999 and Sag 2010 – assume a list-valued feature.)

(42)
$$\begin{bmatrix} \text{PHON} & \langle\rangle \\ \text{SYNSEM} & \begin{bmatrix} \text{LOCAL} & \boxed{1} \\ \text{NONLOC} & \begin{bmatrix} \text{INHER}|\text{SLASH} & \langle \boxed{1} \rangle \\ \text{TO-BIND}|\text{SLASH} & \langle\rangle \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

The LOCAL value of the trace is not constrained at all. Hence it is compatible with whatever is required in a given context. In the example under discussion the trace is used in the place of the object. The verb *dislikes* selects an accusative object and by identifying the description in the COMPS list of the verb with the SYNSEM value of the trace, the LOCAL value is more restricted than in the trace in (42). Since the LOCAL value of the trace is identical to the element on the INHER|SLASH list, the information about the missing object is represented in SLASH too. The information is passed upwards and identified with the LOCAL value of the filler. Since the LOCAL value of the filler is identical to the SLASH element of the trace and hence also identical to the LOCAL value of the trace, syntactic and semantic constraints of the governing verb can be checked as if the combination of *people like him* and *dislike* happened locally.

The percolation of nonlocal features is taken care of by the following principle:

(43) Nonlocal Feature Principle: For each nonlocal feature, the INHERITED value of the mother is the union of the INHERITED values of the daughters minus the TO-BIND value on the head daughter.

This explains the introduction of the nonlocal dependency and the percolation of the information. What is missing is an immediate dominance schema that binds off the nonlocal dependency. This schema is given as the Head-Filler Schema in (44).

(44) Head-Filler Schema:
head-filler-phrase ⇒

$$\left[\begin{array}{ll} \text{HEAD-DTR} & \left[\begin{array}{ll} \text{LOC|CAT} & \left[\begin{array}{ll}\text{HEAD} & \left[\begin{array}{l}\text{VFORM } \textit{fin}\\ \textit{verb}\end{array}\right]\\ \text{SUBJ } \langle\rangle & \\ \text{COMPS } \langle\rangle & \end{array}\right]\\ \text{NONLOC} & \left[\text{TO-BIND|SLASH } \langle \boxed{1} \rangle\right]\end{array}\right]\\ \text{NON-HEAD-DTRS} & \left\langle \left[\begin{array}{l}\text{LOC } \boxed{1}\\ \text{NONLOC|INHER|SLASH } \langle\rangle\end{array}\right]\right\rangle\end{array}\right]$$

This schema licenses combinations of a finite clause (a linguistic object that is fully saturated) with another element that has the same LOCAL properties as the element in the list under TO-BIND|SLASH. Due to the specification of the TO-BIND|SLASH value the SLASH information is not projected any further in the tree, but is bound off in the head-filler phrase.

5 Lexical rules

Since HPSG is a lexicalist theory, the lexicon plays an important role. The lexicon is not just a prison for the lawless as suggested by Di Sciullo and Williams (1987, 3), but is structured and lexical items are related to each other. One means of capturing generalizations is lexical rules. A lexical rule says if there is a lexical item with certain properties then there is also another lexical item with certain other properties. An example for the application of lexical rules is morphology (Pollard and Sag, 1987, Chapter 8.2; Orgun, 1996; Riehemann, 1998; Ackerman and Webelhuth, 1998; Kathol, 1999; Koenig, 1999). The HPSG lexicon (of inflecting languages) consists of roots that are related to stems or fully inflected words. The derivational or inflectional rules may influence part of speech (e.g. adjectival derivation) and/or valence (*-able* adjectives and passive). (45) is an example for a lexical rule. It was suggested by Kiss (1992) to account for the personal passive in German. (For a more general passive rule that unifies the analyses of personal and impersonal passives see Müller 2002, Chapter 3. This more general rule for the passive uses the distinction between structural and lexical case.) The rule takes as input a verbal stem that governs both a nominative and an accusative. The nominative argument is not represented in the

COMPS list of the output. The case of the object is changed from *acc* to *nom*. The remaining arguments (if there are any) are taken over from the input ($\boxed{3}$).

(45) Lexical rule for the personal passive following Kiss (1992):

$$\begin{bmatrix} \text{PHON } \boxed{1} \\ \text{SYNSEM}|\text{LOC}|\text{CAT} \begin{bmatrix} \text{HEAD} & \textit{verb} \\ \text{ARG-ST} & \left\langle \text{NP}[\textit{nom}], \text{NP}[\textit{acc}]_{\boxed{2}} \right\rangle \oplus \boxed{3} \end{bmatrix} \\ \textit{stem} \end{bmatrix} \mapsto$$

$$\begin{bmatrix} \text{PHON } f(\boxed{1}) \\ \text{SYNSEM}|\text{LOC}|\text{CAT} \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{VFORM} & \textit{passive-part} \end{bmatrix} \\ \text{ARG-ST} & \left\langle \text{NP}[\textit{nom}]_{\boxed{2}} \right\rangle \oplus \boxed{3} \end{bmatrix} \\ \textit{word} \end{bmatrix}$$

The stem is mapped to a word and the phonology of the input ($\boxed{1}$) is mapped to the passive form by a function f.

During the past decades there has been some discussion concerning the status of lexical rules. One way to formalize them is to simply use the formalism of typed feature structures (Krieger and Nerbonne, 1993, Chapter 7.4.1; Copestake and Briscoe, 1992; Briscoe and Copestake, 1999; Meurers, 1995, 2001; Riehemann, 1998). In one type of such feature structure-based proposals, the input of the lexical rule is a daughter of the output. This is basically equivalent to a unary branching immediate dominance rule. (46) shows the lexical rule in (45) in a format that directly reflects this approach.

(46) Lexical rule for the personal passive (formalized with typed feature descriptions):

$$\begin{bmatrix} \text{PHON } f(\boxed{1}) \\ \text{SYNSEM}|\text{LOC}|\text{CAT} \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{VFORM} & \textit{passive-part} \end{bmatrix} \\ \text{ARG-ST} & \left\langle \text{NP}[\textit{nom}]_{\boxed{2}} \right\rangle \oplus \boxed{3} \end{bmatrix} \\ \text{LEX-DTR} \begin{bmatrix} \text{PHON } \boxed{1} \\ \text{SYNSEM}|\text{LOC}|\text{CAT} \begin{bmatrix} \text{HEAD} & \textit{verb} \\ \text{ARG-ST} & \left\langle \text{NP}[\textit{nom}], \text{NP}[\textit{acc}]_{\boxed{2}} \right\rangle \oplus \boxed{3} \end{bmatrix} \\ \textit{stem} \end{bmatrix} \\ \textit{acc-passive-lexical-rule} \end{bmatrix}$$

An advantage of this formalization is that lexical rules are constraints on typed feature structures and as such it is possible to integrate them into an inheritance hierarchy and to capture generalizations over various linguistic objects. See Section 7 on inheritance hierarchies and generalizations.

For instance it was argued by Höhle (1997) that complementizers and finite verbs form a natural class in German.

(47) a. dass Karl das Buch liest [German]
that Karl the book reads
'that Karl reads the book'

b. Liest Karl das Buch?
reads Karl the book
'Does Karl read the book?'

In head-movement-inspired approaches (Kiss and Wesche, 1991; Kiss, 1995; Meurers, 2000) the verb in (47b) is related to a lexical item for the verb as it occurs in (47a) by a lexical rule. The complementizer and the lexical rule are subtypes of a more general type capturing the commonalities of *dass* in (47a) und *liest* in (47b).

6 Idioms and phrasal lexical items

While early treatments of idioms assumed that they are just complex words, it has been pointed out by Nunberg, Sag and Wasow (1994) that there are different types of idioms and that there are rather flexible classes of idioms. Some allow passivization, some allow for fronting of idiom parts, some relativization and so on, while others like *kick the bucket* are frozen and loose their idiomatic interpretation when they are passivized or rearranged in a different way. (48) shows some examples of fronting and relativization of the idiom *pull strings*.

(48) a. *Those strings, he wouldn't pull for you.*
b. *Pat pulled the strings* [*that got Chris the job*].
c. *The strings* [*that Pat pulled*] *got Chris the job.*

For examples like *pull strings* Sag (2007) suggested a lexical analysis in the framework of Sign-Based Construction Grammar, which is a version of HPSG. Sag assumes a special lexical entry for *pull* that selects *strings* and ensures that *strings* contributes an idiomatic *strings* relation (*i_strings_rel′*). The special lexical item for *pull* contributes an idiomatic *pull* relation (*i_pull_rel′*). The analysis is translated into the feature geometry that is used in this overview article as follows:

(49)
$$\begin{bmatrix} \text{PHON} & \langle \textit{strings} \rangle \\ \text{SYNSEM} & \begin{bmatrix} \text{LOC} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{LID} \; \boxed{1} \; \textit{strings\_rel} \,/_p\, \textit{l\_strings\_rel} \\ \textit{noun} \end{bmatrix} \\ \text{SPR} & \langle \text{DET} \rangle \\ \text{COMPS} & \langle\rangle \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{IND} & \boxed{2} \\ \text{RELS} & \left\langle \boxed{1} \begin{bmatrix} \text{INST} \; \boxed{2} \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

strings_rel is a type that has two subtypes: one for the literal reading of *strings*, namely *l_strings_rel* and one for the idiomatic reading, namely *i_strings_rel*. The specification above says that the meaning of *strings* is *l_strings_rel′* in the default case. This is marked with the $/_p$. The little *p* stands for *persistent* and indicates that this default is not resolved in the lexicon but remains in the syntax. See Lascarides and Copestake, 1999 for defaults in HPSG. The default may be overridden and such an overriding is enforced in the lexical item of the idiomatic *pull*, which is given as (50):

(50)
$$\begin{bmatrix} \text{PHON} & \langle \textit{pull} \rangle \\ \text{SYNSEM} & \begin{bmatrix} \text{LOC} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{ARG-ST} & \langle \text{NP}_i, \text{NP[LID } \textit{i\_strings\_rel}]_j \rangle \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{RELS} & \langle \textit{ i\_pull\_rel(i,j)} \rangle \end{bmatrix} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

The idiomatic lexical item for *pull* requires the LID value of the selected NP to be *i_strings_rel*. It is therefore ensured that this lexical item for *pull* is combined with the noun *strings* and not, for instance, with *books* and the default specification for the semantic contribution of *strings* that is specified in (49) is overridden.

This brief sketch shows that a lexical analysis works well for some idiom classes and such lexical analyses have been suggested in other frameworks too (see for instance G. Müller 2011 on a Minimalist analysis). Of course there are several other kinds of idioms and this brief overview article can not do justice to the colorful world of idioms. The interested reader is referred to Sailer, 2000 and Soehn and Sailer, 2008 for an extensive discussion of idioms and various instances of relations between idiom parts.

While this type of lexical analysis can also be extended to non-flexible idioms like *kick the bucket* this is usually not done in HPSG. The lexical analysis would involve an expletive with the form *bucket* (see G. Müller 2011), which is rather unintuitive. A further problem for the lexical analysis is that it does not extend to idioms that stretch clause boundaries, since under standard assumptions heads do not select arguments of arguments. However, as Richter and Sailer (2009) pointed out, such idioms exist. For instance, the German example in (51) requires a complement clause with verb second position in which the patient of the kicking relation is fronted and expressed as a pronoun that is coreferent with the subject of the matrix clause, that is, the one who utters the sentence. The matrix verb has to be *glauben* 'to believe' or *denken* 'to think'.

(51) Ich glaube, mich / #dich tritt ein Pferd. [German]
I believe me you kicks a horse
'I am very surprised.'

What is needed here is an extended domain of locality. This is generally the strength of Tree Adjoining Grammar (TAG) (see Abeillé 1988; Abeillé and Schabes 1989 on idioms in TAG), but the TAG analyses can be taken over to HPSG: Richter and Sailer (2009) developed an account for the analysis of sentences like (51) that uses a phrasal lexical entry. The gist of the analysis is that one uses partially specified feature descriptions to constrain the aspects of the idiom that are fixed. The respective AVMs can describe a tree with some non-terminal tree nodes fixed, with some terminal nodes fixed, or with both terminals and non-terminals fixed. In the case of the example above, there has to be a head-filler phrase in which the filler is a pronoun with accusative case that is an argument of *treten* 'to kick' and there has to be an indefinite NP with the head noun *Pferd* 'horse'. It is possible to use regular expressions involving the daughter features. For instance, HEAD-DTR+ stands for one or more occurrences of the feature HEAD-DTR. This allows for an underspecification of structure: while HEAD-DTR refers to a node that is directly embedded in a certain structure – as for instance *man* in *the man*, see (13) – HEAD-DTR|HEAD-DTR refers to a head that is embedded two levels deep – as *man* in *the* [*happy man*]. So one can leave open the exact number of embeddings and just require that there has to be a head of a certain kind. This allows for adjuncts or arguments to be realized along the head path provided no other constraints in the grammar are violated.

I hope to have shown that HPSG is well-equipped to handle various types of idioms, something that plays an important role in current theorizing. See for instance Jackendoff, 1997, Chapter 7, Culicover, 1999, Ginzburg and Sag, 2000, 5, Newmeyer, 2005, 48, and Kuhn, 2007, 619 on the arbitrariness of the Core/Periphery distinction and consequences for linguistic theories.

7 Generalizations

HPSG is a theory that places a lot of information in the lexicon. For instance lexical entries of verbs contain detailed descriptions of their arguments, they contain information on how arguments are linked to the semantic contribution of the verb, information about semantic roles and so on. A good way to capture generalizations with respect to this lexical knowledge is to use type hierarchies with multiple inheritance (Pollard and Sag, 1987, Chapter 8.1). Sag (1997) argued for several different immediate-dominance schemata for variants of English relative clauses and modified the feature geometry of HPSG in a way that made it possible to capture the generalizations over the various schemata in an inheritance hierarchy. Figure 27.14 gives an example of how (a part of) an inheritance hierarchy that includes both lexical and phrasal types may look.

(52)

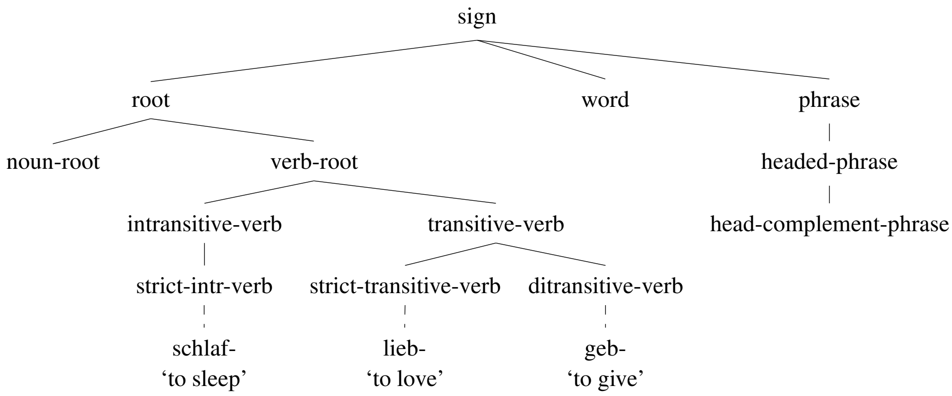


Figure 27.14: Part of an inheritance hierarchy that contains lexical entries and immediate dominance schemata

In Section 2.5 we discussed constraints on phrases of type *headed-phrase*. Since structures of the type *head-complement-phrase* are a subtype of *headed-phrase*, they inherit all the constraints from their supertype. Hence, head features at the mother node of a head-complement phrase are identified with the head features of the head daughter. Similarly the constraint that there is an nominative and an accusative object is represented at the type *transitive-verb*. The type *strict-transitive-verb* adds the information that there is no further argument and the type *ditransitive-verb* adds the information about an additional dative argument.

It should be noted that such inheritance hierarchies cannot capture all generalizations that one wants to capture in a grammar. Inheritance hierarchies do capture so-called vertical generalizations, but horizontal generalizations are left to lexical rules (Meurers, 2001): It was argued by Krieger and Nerbonne (1993), Koenig (1999), and Müller (2006, 2010) that all linguistic phenomena that interact with valence and/or derivational morphology should be treated by lexical rules rather than inheritance hierarchies. The reason for this is that these phenomena can be iterated as for instance in *great-great-grandfather* or *preprepreversion*. The double combination of a prefix with a stem cannot be handled by inheritance, since inheriting information about the presence of a prefix twice would not add new information. In contrast a lexical rule can combine a stem with an affix and apply recursively to its output, for instance, adding *pre-* to *preversion*.

Hence, both lexical rules and inheritance hierarchies are needed.

8 Convergence of theories and differences

It is interesting to see that various theories converge on similar analyses despite differences regarding fundamental assumptions. For instance many analyses in GB/MP, LFG, TAG, and HPSG assume a head-movement analysis for German or something that is equivalent. The "base-generation" approach to constituent order that assumes that arguments can be combined with their head in any order (see Section 2.4) can also be found in Minimalist work (Fanselow, 2001). Since it was argued that movement-based analyses make wrong predictions with respect to quantifier scope (Kiss, 2001, 146; Fanselow, 2001, Section 2.6) and that feature-driven, movement-based accounts of constituent order make wrong predictions (Fanselow, 2003), the base-generation analyses seem to be the only option.

Furthermore, the importance of phrasal constructions has been noted across frameworks (Sag, 1997; Ginzburg and Sag, 2000; Culicover and Jackendoff, 2005; Jackendoff, 2008; Jacobs, 2008) and inheritance hierarchies have been found to be a good tool to capture generalizations (HPSG, CxG, Simpler Syntax, LFG, some versions of CG, and TAG). However, the question to what extent phrasal constructions should be used in linguistic descriptions is currently under discussion. Goldberg (1995, 2006), Goldberg and Jackendoff (2004), Culicover and Jackendoff (2005), Alsina (1996), and Asudeh, Dalrymple and Toivonen (2008) suggest analyzing resultative constructions and/or caused motion constructions as phrasal constructions. As was argued in Müller, 2006 this is incompatible with the assumption of Lexical Integrity, that is, that word formation happens before syntax (Bresnan and Mchombo, 1995). Let us consider a concrete example, such as (53):

(53) a. Er tanzt die Schuhe blutig / in Stücke. [German]
he dances the shoes bloody into pieces
'He dances the shoes bloody / into pieces.'

b. die in Stücke / blutig getanzten Schuhe
the into pieces bloody danced shoes
'the shoes that were danced bloody/into pieces'

c. * die getanzten Schuhe
the danced shoes

The shoes are not a semantic argument of *tanzt* 'dances'. Nevertheless the NP that is realized as accusative NP in (53a) is the element the adjectival participle in (53b) predicates over. Adjectival participles like the one in (53b) are derived from a passive participle of a verb that governs an accusative object. If the accusative object is licensed phrasally by configurations like the one in (53a) it cannot be explained why the participle *getanzte* can be formed despite the absence of an accusative object. See Müller, 2006, Section 5 for further examples of the interaction of resultatives and morphology. The conclusion, which was drawn in the late 70s and early 80s by Dowty (1978, 412) and Bresnan (1982, 21), is that phenomena that feed morphology should be treated lexically. The natural analysis in frameworks like HPSG, CG, CxG, and LFG is therefore one that assumes a lexical rule for the licensing of resultative constructions. See Verspoor, 1997; Wechsler, 1997; Wechsler and Noh, 2001; Kay, 2005 and Simpson, 1983 for lexical proposals in some of these frameworks.

If resultative constructions are lexical constructions, one needs rather abstract schemata for the combination of the respective lexical items. The grammatical examples in (53) are licenced by the rather general schemata for head-complement phrases and head-adjunct phrases that are assumed in HPSG. As I have shown in Müller, 2013c, the Head-Specifier Schema and the Head-

Complement Schema can be seen as formalized versions of External Merge and the Head-Filler Schema as a version of Internal Merge as assumed in the Minimalist literature and informaly stated in Chomsky (2008, 2013). So, the truth seems to lie somewhere in the middle: on the one hand we need phrasal constructions for some of the phenomena that Jackendoff and others discussed, e. g. the NPN-construction (Jackendoff, 2008), but on the other hand we need abstract schemata for combining lexical items.

While there are many commonalities between frameworks and the descriptive tools that are used, there are huge differences in the ways arguments for the specific analyses are stated. Given the evidence that has accumulated over the past few decades it cannot be ignored any longer that Chomsky's claims regarding innateness of language-specific knowledge are too strong. For instance Bod (2009) shows that Chomsky's Poverty of the Stimulus argument (Chomsky, 1971, 29–33) is not convincing since the appropriate grammars can be acquired from the input even if the input does not contain sentences of the type Chomsky claims to be necessary for correct acquisition. Gold's formal proof that natural languages are not identifiable in the limit from positive data (Gold, 1967) was shown to be irrelevant for the problem of language acquisition (Pullum, 2003; Johnson, 2004). All other arguments for innate linguistic knowledge have been challenged too. See for instance Tomasello, 1995, 2003; Dąbrowska, 2004; Goldberg, 2004, 2006 and Müller, 2013b for an overview. While early publications in HPSG assumed a theory of UG, researchers are much more careful nowadays as far as claims regarding innateness are concerned. A consequence of this is that theoretical entities are only stipulated if there is language internal evidence for them (Müller, 2013a), that is, if it is plausible that language learners can acquire knowledge about certain linguistic objects or structures from their input. To take an example, empty nodes for object agreement (AgrO) in German cannot be justified on the basis of object agreement data from Basque. German does not have object agreement and hence AgrO is not assumed to be an entity of grammars of German. While Fodor's work on UG-based language acquisition (1998) is compatible with HPSG, recent work on language acquisition tries to explain language acquisition without recourse to innate linguistic knowledge (Green, 2011). The insights of Tomasello (2003) and Goldberg et al. (2004) can be directly transferred to a Greenian approach. For details see Müller, 2013b, Section 11.4.4, Section 11.11.8.1.

Another important point in comparing frameworks is that HPSG is a model theoretic and hence a constraint-based approach (King, 1999; Pollard, 1999; Richter, 2007). HPSG shares this view with certain formalizations of LFG (Kaplan, 1995), GPSG (Gazdar et al., 1988; Rogers, 1997), GB (Rogers, 1998), and the Minimalist Program (Veenstra, 1998). In model theoretic approaches, well-formedness constraints on objects are formulated. Everything that is not ruled out explicitly is allowed. As Pullum and Scholz (2001) pointed out, this makes it possible to assign structure to fragments of utterances, something that is impossible for generative-enumerative approaches, which enumerate an infinite set of well-formed utterances. Since partial phrases as for instance *and of the* from (54) are not in this set, they do not get a structure.

(54) *That cat is afraid of the dog and of the parrot.*

Furthermore increased markedness of utterances can be explained with reference to the number and strength of violated constraints. Gradedness has not been accounted for in generative-enumerative approaches. Chomsky's attempts to introduce gradedness into Generative Grammar (1964) are discussed in detail by Pullum and Scholz (2001, 29).

Another advantage of surface-oriented constraint-based theories is that they are compatible with performance models (Sag and Wasow, 2011). Psycholinguistic experiments have shown that hearers use information from phonology, morphology, syntax, semantics, information structure, and world knowledge in parallel (Crain and Steedman, 1985; Tanenhaus et al., 1996). This is evidence against strong modularity in the sense of Fodor (1983) and therefore against theories that assume that the phonological realization of an utterance is the spell-out of a syntactic structure and the meaning is the interpretation of the syntactic structure. Rather constraints from all descriptive levels interact and are used for parsing and disambiguation as soon as the relevant information is available to the hearer. In particular interpretation is not delayed to the end of a phrase or a phase (see Chomsky 2008 on Phases and Richards 2014 for several different approaches to transfer of linguistic objects to the semantics component that is assumed in Minimalism).

9 Conclusion

This brief introduction to HPSG showed that typed feature descriptions can be used to formulate constraints on all linguistic aspects. In particular it was shown how to capture valence, dominance and precedence, long-distance dependencies, and the linking between syntax and semantics. It was discussed how lexical rules (described with typed feature descriptions) can be used to analyze morphological phenomena and how certain idioms can be analyzed lexically while others require a flexible conception of the lexicon that includes phrasal lexical items among the entities stored in the lexicon. Pointers to publications dealing with phonology and information structure were provided. Due to the uniform representation of all information as feature value pairs, generalizations regarding roots, words, lexical rules, and phrases can be captured by inheritance hierarchies. The consistency of many of the analyses has been verified in small-, medium-, or large-scale computer implementations.

I hope to have shown that HPSG is a full-blown framework that has worked out analyses on every linguistic level. It can be paired with psycholinguistically adequate performance theories and is compatible with results from language acquisition research. Hence HPSG fulfills all the desiderata for a cognitively plausible linguistic theory.

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