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Frames at the Interface of Language and Cognition

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Abstract

The article reviews the work on frames in the last decade in a Düsseldorf research group. The research is based on Barsalou's notion of frame and the hypothesis that this is the general format of categorization in human cognition. The Düsseldorf frame group developed formal definitions and interpretations of Barsalou frames and applied the theory in linguistics, philosophy, and psychology. Focus here is on applications in semantics. The Düsseldorf approach grounds the analysis of composition on deep decomposition of lexical meanings with frames. The basic mechanism of composition is unification. This has deep repercussions on semantic theory and practice: composition produces structured meanings and is not necessarily deterministic. The interaction of semantic and world knowledge can be modeled in an overall frame model across levels of linguistic analysis. The review concludes with a brief report on developments of hyperframes for dynamic verbs and for cascades, a model for multi-level categorization of action.

1. FRAMES

1.1. Frames and frames

The notion of ‘frame‘ is notoriously vague. It has been used in different traditions in very different senses. There is the tradition that considers frames some kind of complex of background knowledge which lends a given concept its frame-specific sense. One exponent of this notion is Fillmore and his Frame Semantics. “The basic assumption of Frame Semantics, in respect to word meanings, is that […] essentially *all* content words [footnote omitted] require for their understanding an appeal to the background frames within which the meaning they convey is motivated and interpreted.” (Fillmore & Baker 2010: 318). This notion of frame has been taken up in major branches of cognitive linguistics (cf. Croft & Cruse 2004: Ch. 2). In Fillmore’s work you will, however, not find a rigid definition of frames and their structure. In the huge online data collection FrameNet[1] that presently (July 2020) describes 13,600 word senses and the frames they belong to, the frames are described in prose.

A second tradition has its origin in cognitive science and artificial intelligence, notably in the seminal work by Marvin Minsky (1974). Minsky’s frames are meant to model distinct chunks of knowledge in human cognition. They are networks of nodes and relations between them; they already have the crucial traits of attributes (“slots”) and values (“fillers”). Most importantly, frame structure is recursive: values of attributes of a node can carry attributes of their own. Minsky’s notion of frames was taken up in cognitive psychology, most prominently by Lawrence Barsalou (1992a, b). Another line of derivative developments emerged in artificial intelligence and in formal linguistics, in approaches such as Lexical Functional Grammar (LFG, Bresnan 2001) and Head-Driven Phrase Structure Grammar (HPSG, Pollard & Sag 1994). These formalisms use recursive attribute-value structures for representing syntactic and other linguistic structures. It is this tradition of frame theory and application from which the work developed that will be reported in this article.

1.2. The frame hypothesis

Barsalou ventured the claim that frames are the *general* format of concepts in cognition, a claim that became known as the Frame Hypothesis: “[…] I propose that frames provide the fundamental representation of knowledge in human cognition” (Barsalou 1992a: 21)

He supported the claim with experimental evidence and embedded it in a general theory of cognition (Barsalou 1992b). The frame approach was later developed into his theory of perceptual symbol systems (Barsalou 1999) and situated simulation (2003) which accounts for the way in which conceptual representations are grounded in perception and experience.

Why frames, among all the competing models of categorization? Barsalou & Hale (1993) compare frames to the rival accounts: feature lists, exemplar models, prototype models (of various types), connectionist networks, intuitive theories, and classical models. They show that all these are based on lists of binary features, sometimes with fuzzy or weighted values. While useful for many theoretical purposes, “[f]eature lists can be viewed as a rough approximation to human knowledge. They capture fragmentary aspects of human knowledge, but fail to capture many other aspects. Feature lists are like a few pieces of a dinosaur’s skeleton, discovered by a palaeontologist. They provide hints of the dinosaur’s overall structure, but are far from constituting it completely.” (ibid., p. 135). What makes recursive frames superior to all other known models is their potential for unlimited recursion, and, most of all, their being based on relations (“attributes”) that can take arbitrary values. In addition to their richer basic structure, frames can be invested with various kinds of constraints that restrict the values a particular attribute may take, correlate the values of attributes, add invariant

[1] https://framenet.icsi.berkeley.edu/fndrupal/

relations between the values of different attributes, or subject the whole frame to conditions that adapt it to given circumstances.[2] Barsalou and Hale admit, however, that "cognitive psychologists have little methodology for extracting recursive frames from human knowledge and verifying their presence." (Barsalou & Hale 1993: 136).

This was the state of the art in the early 1990s. Meanwhile, a substantial breakthrough was provided by Binder et al. (2016). They established a "basic set of approximately 65 experiential attributes based on neurobiological considerations, comprising sensory, motor, spatial, temporal, affective, social, and cognitive experiences" (p. 1). For these attributes "there are likely to be corresponding distinguishable neural processes" (p. 5). The conceptual components they isolated turned out to be largely independent of each other; thus, they are likely to correspond to different attributes in frame formation. For each of these components, association ratings were elicited for 434 nouns, 62 verbs and 39 adjectives, resulting in vectors with 65 dimensions for each word. The study produced strikingly different vector patterns for intuitively different groups of words. While this does not mean that concrete frames were established for single words, the study proved that attributes (in the sense of frame theory) are necessary and characteristic for the semantic representation of verbal concepts.

1.3. Evidence for frames

The strong claim of the Frame Hypothesis calls for justification. From a psychological point of view, the complexity and descriptive power of human cognition clearly requires a theory beyond binary features, a theory based on attributes and permitting recursion (see Barsalou 2017 for a more recent statement to this extent). In addition to the results from psychology, there is broad indirect evidence that categorization in terms of Barsalou's frames is the model of choice. Löbner (2014) presents evidence from human language, including the following points:

- Syntactic constituent structures and dependency structures are essentially frames.
- Grammatical features such as number, case, or tense can only be applied once, and hence are values of corresponding attributes.
- It is commonly established that verbs are associated with semantic roles. These correspond to attributes in event frames.
- Modern natural language lexica have been developing a growing set of attribute terms.

More indirect evidence is provided by the widespread use of frames in various fields of life. Apart from scientific application in numerous disciplines, frames are firmly established in social practice wherever information is organized in standardized formats such as the description of persons in identity documents, of items in databases in the form of tables (each table column corresponds to an attribute), of books in catalogue entries, etc. Every official form, like a tax declaration, any questionnaire is nothing but a frame with slots for the values of some explicit or implicit attributes to be filled in (see Löbner 2013: 302–305 for passports as frames in practical use).

1.4. Düsseldorf frames

1.4.1. The general design. A larger research community in Düsseldorf[3] developed Barsalou's notion of frame into a formal theory with broad application. I will give only an informal presentation of

[2] See Barsalou (1992a, p. 35–40) on structural invariants, attribute constraints, contextual constraints, value constraints, and optimizations.

[3] The research was conducted in the Research Unit FOR 600 "Functional concepts and frames" (2005–2011) and the Collaborative Research Centre SFB 991 "The structure of representations in language, cognition, and science" (2011–2020) both funded by the German Science Foundation (DFG). The projects comprised researchers from linguistics, computational linguistics, psycholinguistics, psychology, neurology, philosophy,

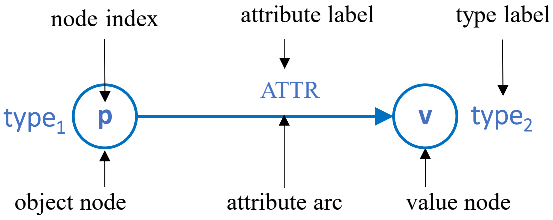

Figure 1

The basic unit of a Düsseldorf frame graph

what became to be called "Düsseldorf frames" (D-frames for short). For formal definitions see Petersen (2007/2015), Kallmeyer & Osswald (2013) and Löbner (2017).[4] I will use graphs for frame representation. AVMs (attribute value matrices) are preferred by authors from formal linguistics.

A distinctive feature of Düsseldorf frame theory is the following restriction and clarification:

(1) Attributes in frames are functions.

In his writings on frames, Barsalou does not explicitly assume functionality, but in all examples he mentions, the attributes are in fact functional.[5] Functionality means that for a given possessor an attribute necessarily takes a unique value (which may be underspecified in the frame); it also has the consequence that any element in a frame can carry a particular attribute only once. For the metalanguage, functionality of attributes requires words denoting functions such as functional nouns (Löbner 2015) or stative dimensional verbs like *cost*, *weigh*, *be called* (Gamerschlag 2014, Schwarze & Geisler 2015).

The basic unit of graph representations of D-Frames is depicted in Figure 1. Nodes stand for individuals in the underlying ontology; they are labeled with indices; they may carry type labels, where types correspond to individuals or sets of individuals in the ontology.[6] The arrow represents an attribute that maps individual to individuals. It carries a specific attribute label. The content of a basic unit is the conjunction of the following conditions:

(2) **Meaning of the basic frame unit**

(a1)	p carries the attribute ATTR	(a2)	the value of the attribute for p is v
(t1)	p is of the type $type_1$	(t2)	v is of the type $type_2$

Conjunct (a2) presupposes (a1), but is worthwhile stating since no attribute is defined for all types of entity in the ontology. Since type assignments are optional, so are conjuncts (t1) and (t2). Note, however, that type conditions for p and v are also provided by (a1) and (a2), respectively: p is of the type that ATTR is defined for, and v is of the type the attribute returns.

and the history of medicine. The research of the CRC is currently continued in the DFG projects "Hierarchical frame induction via probabilistic models" (Laura Kallmeyer), "The interaction of noun and verb frames in light verb constructions" (Jens Fleischhauer), "The semantics of derivational morphology: A frame-based approach (Ingo Plag), "A frame-based analysis of countability" (Hana Filip), and "Coercion and copredication as flexible frame composition" (Laura Kallmeyer, Rainer Osswald).

[4] Kallmeyer & Osswald, unlike Petersen and Löbner, admit relations as frame elements in addition to attributes; these are restricted to nodes accessible by attribute links. In principle, they can be replaced by multi-place functional attributes as introduced in Löbner (2017) and illustrated in examples in Figure 2 and Figure 4.

[5] An apparent counterexample is the attribute COLOR because, loosely speaking, an object can be more than one color, for example being striped. We use the attribute COLOR as presupposing monochromaticity; for a striped object, the possessors of the COLOR attribute would be the single stripes. See Löbner (2017: 109) for homogeneity conditions on attributes.

[6] For a formal definition of a frame ontology see Löbner (2017: 103f, 109).

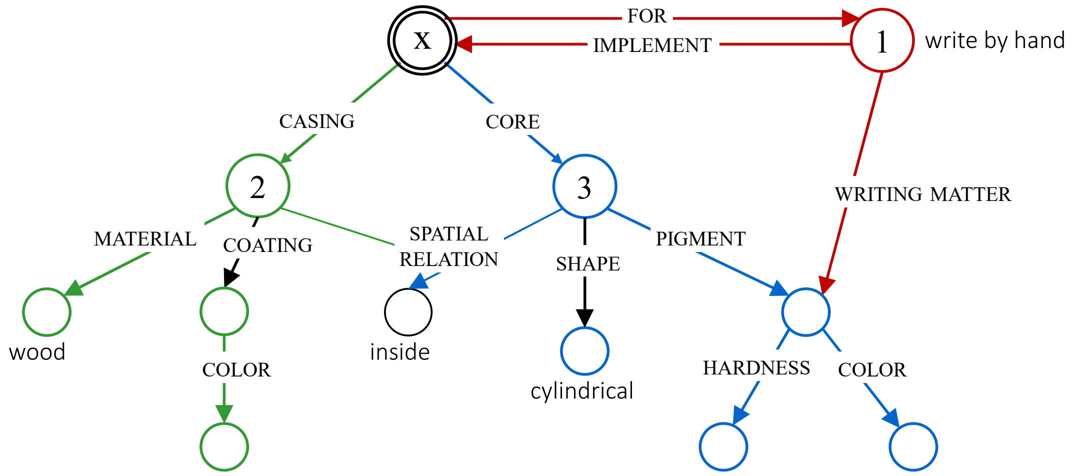

Figure 2

D-Frame for a pencil

A frame structure is a coherent network of basic units such as the example to follow. Due to the composition of the basic unit, only connections between nodes are possible, not between attributes.[7] Attributes can form chains, though, out of basic units; technically these are chains in terms of functional composition. The content of a frame out of more than one unit derives from (2): For each attribute application in the frame, there is a condition according to (2); the content of the whole frame is the conjunction of all these conditions. Thus, frame structures are strictly first-order in the sense of predicate logic.[8]

1.4.2. An example. Figure 2 gives a frame for a pencil. The node for the subject of the frame, i.e. for what it represents, is conventionally marked with a double line. It does not receive a specific type label because its type derives from the totality of conditions in the frame; these are all related in one or more steps to the subject node (I'll use the term "main node", often it is called the "central node"). The pencil has three attributes, CASING, CORE, and FOR. CASING and CORE are "part-of attributes"; they connect a whole to a unique part of it (i. e. a constitutive part, not just an arbitrary portion), here its casing and its core, represented by nodes 2 and 3. The core is inside the casing which is captured by the two-place attribute[9] SPATIAL RELATION and the value inside; the value it takes is one out of a limited set of mereotopological relationships in 3-dimensional space (see Varzi 1996).

The third attribute FOR is an affordance attribute.[10] It connects a physical object to a type of action it can figure in. For artefacts this will usually be the purpose they are made for; here the affordance is specified as writing by hand. An affordance attribute is always accompanied by a converse attribute that specifies the semantic role of the object in this type of action, here the role of implement. A further semantic role attribute specifies the pigment of the core as the writing matter. The affordance attribute belongs to the sub-class of attributes that take events as values. Semantic roles of events belong to a fourth type of attribute, so-called "correlate" attributes. (Semantic role frames for events,

[7] In Barsalou (1992a), the basic graphic unit has also a node for the attribute, and attribute nodes can be nested. It can be shown, however, that Barsalou's attribute–attribute links are in fact attribute–value–attribute links and should be represented as such (Petersen 2007/2015, Löbner 2015).

[8] A simple first-order predicate logic language for describing frame structures is formally defined in Löbner (2017: 104f). Other authors use other types of formal languages, for example Babonneau et al. (2016), Kallmeyer & Osswald (2013), Naumann (2013), Naumann & Petersen (2015), Naumann et al. (2018).

[9] See Löbner 2017 for n-ary attributes.

[10] Affordances were introduced to frame theory in Werning (2008). For further elaboration see Vosgerau et al. (2015) and Seuchter (2020).

called "case frames", go back to Fillmore 1968). I skip the attributes of the daughter and grandchild nodes of the main node.

Due to the recursivity of the frame, any element in the frame, except the frame subject itself, is the subject of a subframe (the casing frame, the core frame, the writing frame, etc.). Typically, the recursion will be limited for practical reasons, but some of the dependent nodes lend themselves to further elaboration. If the frame is to be taken as a general categorization of pencils, we will not fix the values for the attributes we left unspecified, like the color of the coating. Likewise, the writing subframe could be further elaborated with the writer and the text written as additional semantic roles, but it does not matter for the general categorization of a pencil who writes with it and what.

The frame contains a cycle (between nodes x and 1); this kind of cycle occurs inevitably with affordance attributes. There are other cases, such as the notion 'singer-songwriter', that require cyclic frame structure. Thus, acyclicity is not a psychologically plausible option for natural language semantic frames. Formalisms such as HPSG exclude cyclic frames for technical reasons.

Any frame can be read in two ways: as the representation of an individual entity, i.e. a token, or as the general representation of a category, i.e. a type, in terms of what its members are like. In other words, a frame represents its subject as a token-of-a-type. Underspecification or non-specification leaves room for variation within the category; additional information might narrow down the description to a unique object, in which case there would be only one token of the type. Still, there is the level of type and the level of token, to be carefully distinguished.

The pencil frame is not a lexical frame for the word *pencil*; it is too specific: for example, mechanical pencils are excluded by this description. Nevertheless, the frame can be taken as a tentative proposal as to what lexical frames might be like.

In this article, I will concentrate on the application of Düsseldorf frame theory to semantics. Apart from semantics, D-frames have been studied and applied in various disciplines, among them:

- Philosophy (Berio 2020, Hommen 2018, Seuchter 2020, Strößner et al. 2020, Taylor & Sutton 2020, Vosgerau et al. 2015, Vosgerau & Petersen 2015, Werning 2008, Werning & Maye 2007),
- Philosophy of science (Chen 2014, Schurz & Votsis 2014, Zenker 2014),
- Psychology (Beckmann et al. 2018, Redmann et al. 2014, Redmann 2018),
- Law (Busse 2015, Busse et al. 2018, Wulf 2018).

Frames in general are discussed in Busse (2012) and Kann & Inderelst (2018). Cooper (2020) discusses the relation of frames (in the sense of Fillmore, Barsalou, and D-frames) to his Type Theory with Records.

2. FRAMES IN SYNTAX

AVMs have been used for syntactic analysis in the formalisms LFG and HPSG. Unlike D-frame theory, they are not motivated by cognitive theories of categorization, but by the aim of machine-processing natural language; but clearly, they are very close to a frame approach to language and demonstrate its feasibility for a wide range of linguistic phenomena. For both theories, there are extensive online bibliographies.[11]

For the two classical approaches in syntax, constituent structure and dependency structure, the trees they use are essentially frames structures (Löbner 2014: 28–42). Dependency trees are just frame diagrams as they are. The attributes are of the correlate type; for example, a verb is assigned its correlates subject and direct object. Constituent structure trees can be read as frame diagrams in

[11] For HPSG see https://hpsg.hu-berlin.de/HPSG-Bib/index.html.en,
for LFG, https://ling.sprachwiss.uni-konstanz.de/pages/home/lfg/resources.html for LFG.

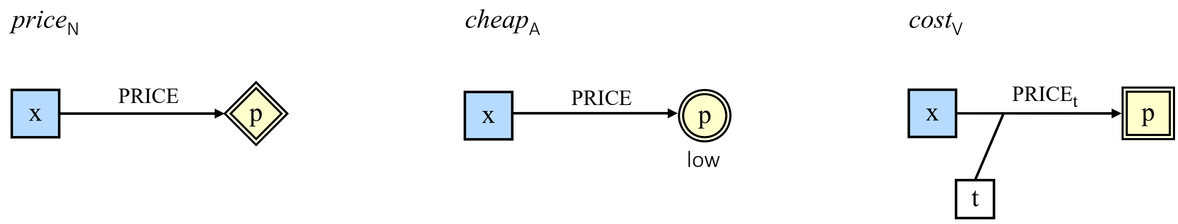

Figure 3

Three frames corresponding to the attribute PRICE

terms of part-of attributes for the constituents. From a formal point of view, dependency structure would be the more natural syntax component in a general D-frame account of language.

The Düsseldorf group did not develop a frame-theoretic syntax component, but used established syntax formats such as LTAG (Lexical Tree-Adjoining Grammar, used by Laura Kallmeyer and collaborators) or RRG (Role and Reference Grammar, used by Robert Van Valin and his group). Both groups, however, use D-frames for the semantic component of grammar.

3. FRAMES IN LEXICAL SEMANTICS

3.1. Decomposition

One of the major assets of Düsseldorf frame theory is the development of frames as a means of lexical decomposition. There is no other framework of conceptual decomposition that would have comparable descriptive power (except for quasi-frame approaches like HPSG); in addition, it is carried by the assumption of the Frame Hypothesis and thus has the potential of providing a cognitive analysis of linguistic meaning. Lexical decomposition is not an end in itself; rather, it provides the basis for much more differentiated theories of the interface between the lexicon and syntax, of semantic composition, of the semantics of word formation, and of the interplay of semantic and world knowledge.

3.1.1. Lexical frames corresponding to a single frame attribute. Since attributes are the primitives of frame formation, all expressions immediately corresponding to attributes can be lexically decomposed in a straightforward way. These include attribute-denoting nouns, stative dimensional verbs and dimensional adjectives. As stated above, attribute-denoting nouns are functional concepts and, conversely, it can be argued that all functional nouns are terms for attributes in some frames or other. Figure 3 displays frames for the meanings of the words *price*, *cheap* and *cost*, which are all immediately related to the attribute PRICE. The frame for the functional noun *price* consists in a single attribute application. The possessor is a relational argument of the noun; the value p of the attribute is the referential argument of the noun and therefore figures as the main node.[12] The frame for any functional noun would be analogous. The second frame decomposes the meaning of the dimensional adjective *cheap* as ‘of low price’. The basic unit is the same, but the interface with grammar differs in that the node p does not have referential status, as adjectives don’t have a referential argument. In the frame for the stative dimensional verb *cost*, the PRICE attribute has an additional time argument. It is necessary for the verbal variant because states are necessarily related to a time.

3.1.2. Event verb frames. Not accidentally, the major focus of lexical analysis has been on event denoting verbs. Their established conceptual structure in terms of semantic roles provides a starting point for frame analysis. The first frame in Figure 4 is a case frame of a motion event with a theme that moves from source to goal. Correspondingly, it has a main node for an event with the attributes THEME, SOURCE and GOAL. The type event of the main node derives from the fact that the three

[12] I distinguish nodes for grammatical arguments by using rectangles; diamonds mark referential nodes.

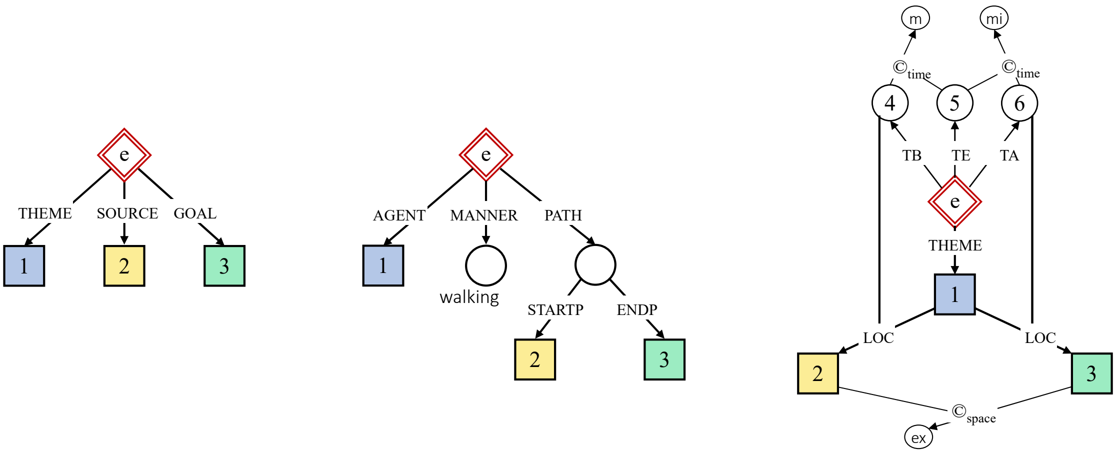

Figure 4

Three verb frames

attributes together will only be defined for events. Case frames are very abstract. They contain little information about the concrete type of event, as they are shared by a broad variety of verbs.

The second frame is taken from Kallmeyer & Osswald (2013), where it is used as a meaning representation of the verb *walk*. The moving object is an agent, whence the event is of the type action. Source and goal are modeled as starting point and endpoint of the path of the movement. There is an additional attribute MANNER with the value walking; this is not a semantic role, and therefore not marked as an argument. It would have to be spelt out for a full lexical analysis, a task not trivial at all. Although conceptually incomplete, the frame is functional in the context of the interplay of syntax and lexical meaning where it was introduced. It is minimally recursive in that it models the relationship between the three semantic roles PATH, SOURCE and GOAL. Let us call it an extended case frame.

The third frame, adapted from Löbner (2017), models the concept underlying the Japanese verb *iku* 'go'. *Iku* is a punctual verb in Japanese, meaning roughly an event of first being at the source, then at the goal; its punctuality manifests in the fact that the verb does not allow progressive aspect (Martin 1975: 518), unlike English *go*. The verb is unspecific with respect to the moving entity and its role; it might be an agent actively moving or just a theme changing place. As with the other two frames, the nodes 1, 2 and 3 represent the moving object, the source, and the goal. The top of the frame invests the event with a temporal structure. The three attributes TB, TE and TA relate the event e to the time before (t_b, node 4), the event time (t_e, node 5) and the time after (t_a, node 6). Two applications of the binary "comparator" attribute $©_{time}$ define the relationships between t_b, t_a and t_e: t_b immediately precedes t_e and t_a immediately follows t_e.[13] The event time t_e is the target of aspect and tense operations on the verb frame. LOC in this frame is a two-place attribute that returns the location *at a given time*. The location of the theme at t_b is the source; its location after the event is the goal. An additional spatial comparator $©_{space}$ relates the two locations: the goal is outside the source. In this way, the third frame makes explicit the crucial relationships between all three arguments and the event time.

The 'iku' frame contains two state frames: the nodes 1, 2, and 4 model the state of the theme being at the source at time t_b; nodes 1, 3, and 6 denote the state after. Thus, this change-of-state frame is essentially composed of the two frames of initial and final state and the relationships between them: (i) they involve the same time-dependent attribute of the moving object; (ii) they relate to an earlier and a later time; (iii) they specify the relationship between the values for these two times. These three conditions hold for arbitrary change-of-state verbs.[14] The 'iku' frame constitutes the rare case of a

[13] m is 'meet' in Allen (1983), i.e. immediate adjacency to a later time; mi is the inverse 'immediately after'.

[14] For more examples see Löbner (2017: 110–115).

lexical verb frame (almost[15]) fully spelt out; this is possible because of the extremely abstract meaning of the verb and its lack of a process component in the concept. Frames for change-of-state verbs with an extended phase of transition require more; we will come back to this aspect in § 5.1.

The three frames in Figure 4 represent different degrees of elaboration. There is the simple case frame with the nodes e, 1, 2, and 3 that is contained as a substructure in the other two frames. It can roughly be regarded as the interface with grammar because it marks the main node and the grammatical arguments. Different degrees of elaboration will be adequate for different aims. In this respect, the use of frames in science is in accordance with what happens in the cognitive system, as emphasized by Barsalou in various places: frames are adjusted so as to meet the needs in a situation and for a purpose; they may be enriched or reduced depending on how much information is needed about which elements in the frame; they may be created for special purposes and will always be restricted for the sake of economy; they will be modulated if demanded.

Frames like the first two are sufficient and economic for studies of the interface between lexicon and grammar. They are used throughout by researchers in the projects that combine LTAG syntax with frame semantics. In this approach, the interplay of syntactic structure with semantics is modeled in tandem. Lexical items are equipped with frame-format meanings and these frames are unified, driven by the syntactic structure in LTAG format (see Kallmeyer & Osswald 2013 for the general idea). These LTAG+frames studies address various types of verb constructions and alternations. They include:

- Zinova (forthc.) on Russian verb prefixes.
- Kallmeyer et al. (2016) on *for*-adverbials and aspectual interpretation,
- Seiffahrt (2019) on the induced-action alternation and the caused-motion construction,
- Fleischhauer et al. (2020) on German light-verb constructions,
- Balogh & Osswald (2020) on verbal particles in Hungarian (using RRG syntax).

In addition to these works, there are several studies on special verb classes that offer deeper decompositional analyses beyond extended case frames or former approaches like those based on Dowty (1979) or Levin & Rappaport Hovav (2005). The latter approaches are focused on meaning components like CAUSE, BECOME etc. that are common to a great number of verbs, with any idiosyncratic content left unanalyzed (Fleischhauer et al. 2017). Idiosyncratic lexical content is what the novel frame analyses aim at. These include work on

- perception verbs such as *taste* and *smell* (Petersen & Gamerschlag 2014),
- German *steigen*, English *rise* in its extensional and intensional uses (Naumann et al. 2018) and its fictive motion use (*the road rises steeply*, Gamerschlag & Petersen 2020)
- position verbs like *sit* (Gamerschlag et al. 2013)
- verbs of sound and substance emission like *drone* and *leak* (Fleischhauer et al. 2019).

3.2. Semantics of word formation

3.2.1. Metonymy and derivation. Metonymy is a phenomenon where D-frames come in very naturally as a framework of analysis. There is agreement that metonymy consists in using an expression for some "source" to refer to a "target", where source and target are related by belonging together in some sense or other (Tyler & Takahashi 2011: 617). Many authors (e.g. Lakoff 1987) have assumed

[15] The only meaning aspect left unaccounted for is the potential of inherent deixis: if the source is left unspecified, it may be the location of the speaker, as similarly with English *go*.

Figure 5

Frames for opera and for paying

that metonymy is a basic cognitive phenomenon, not just a rhetorical trope. In frame theory, metonymy is simply the shift of the referential main node within a given frame to a dependent node, and thereby a shift of reference.

The left diagram in Figure 5 shows a very rudimentary frame for the concept 'opera' in the sense of *opera* as 'a dramatic work in one or more acts, set to music for singers and instrumentalists'.[16] We invest the main node with just two of its attributes, SCORE and PERFORMANCE. Let us assume that the opera is Puccini's "Madama Butterfly", which could be specified by further attributes of node 0, and that the PERFORMANCE attribute associates it with the premiere on 17 Feb 1904 at La Scala in Milano; these two specifications would be added to node 2 in appropriate form.

When we choose node 1 for the main node instead, we receive a frame for the 1904 score of the opera; the value of this node, and the subject of this frame, can be called 'opera', or 'Madama Butterfly', too (cf. *The publisher sent the opera/Madama Butterfly to Puccini very late.*). This is a classic case of metonymy. From node 1 we can get back to node 0 by an inverse of the attribute SCORE because every score is a score of a unique piece of music. In choosing 1 as an alternative main node, we take the same frame information from a different perspective.

We can do the same with the performance we assumed: it, too, can be called metonymically 'the opera' or 'Madama Butterfly'. We capture this concept if we make 2 the main node, thus getting a third perspectivization of the three-node frame. Again, we can get back to node 0 by an invert attribute. The simple example shows the essence of metonymy: a shift of perspective in a given complex frame. Given that our knowledge is organized in a very great number of overlapping and interconnecting frames, this kind of shift is indeed central and fundamental and to be expected ubiquitously in thinking and communicating.

In very many cases of metonymy, the relation between the source and the target is just a frame attribute. There are cases that seem to suggest that this is too restrictive (the type *The museum owns two Morisots*). According to the in-depth study Terhalle (2016), the crucial necessary condition for all types of metonymies is a functional relation, in the given context, of the *target* to the *source*.

The semantic effect of derivation, in particular of nominalization, very often is a shift of the main node of the root's frame to a dependent node just like the shift involved in metonymy. The second frame in Figure 5 is a rudimentary 'pay' frame. If we let 0 be the main node and invest the frame with an action verb interface (i.e. with 0 as the referential node of the type action and 1, 2, and 3 as argument nodes), we receive a case frame for the verb *pay*. With central node 0, but a noun interface, we get a frame for *payment*. A "payment" can also be the money transferred, i.e. what is represented by node 2. Two further metonymic shifts yield the "payer" (node 1) and the "payee" (node 3). Thus, we have the possibility to choose each of the four nodes as the main node and have (in English) the root *pay* or a lexical derivation thereof to denote each of them.

[16] Dictionary entry in Lexico UK Dictionary, https://www.lexico.com.en, as of Apr 16 2020.

There are several frame-based studies on derivational word formation semantics. Schulzek (2019, Ch. 4) analyzed deverbal nouns in German. For English, Kawaletz & Plag (2015) investigated the possible readings of deverbal *-ment* formation, Andreou & Petitjean (2020) scrutinized *-al* formations, and Andreou (2017) presents a frame analysis of the meaning of English stereotype negation like in *non-answer*.

3.2.2. Compounds. The basic mechanism of compounding is frame unification. In the simplest case, the main node of a modifier frame is unified with a dependent node of the head frame and thereby embedded in the host as a subframe. Two common types of NN compounds are value compounds and argument compounds. In a value compound, the main node in the modifier frame is unified with the value of an attribute in the head noun frame. For example, in the compound *plastic bag*, the main node of the 'plastic' frame is unified with the value node of the attribute MATERIAL of the main node in the 'bag' frame. For argument compounds, the target node of unification is an argument node in the frame of a relational head noun. An example would be *book chapter*: the relational argument node in the 'chapter' frame is unified with the main node of the 'book' frame.

Other standard types of compounds are more involved. There is the frequent type "frame compound", where a bridging frame unifies with the frames of both components. For example, the frame for *book shop* can be regarded as the result of integrating the 'shop' frame and the 'book' frame into a 'sell' or 'buy' frame by unifying the main node of the 'book' frame with the theme node and the main node of the 'shop' frame with the location node. Synthetic compounds like *bus driver* involve derivation of the head from a verb; the deverbal head frame contains the case frame of the root verb, and the modifier frame is unified with an appropriate case node therein.[17]

4. FRAMES IN COMPOSITIONAL SEMANTICS AND PRAGMATICS

4.1. Composition

4.1.1. Basic traits of composition in frame theory. Composition with frames differs from the approach taken in formal semantics in fundamental ways:

(i) The basic mechanism is unification.
(ii) Composition is not deterministic.
(iii) Composition accumulates and integrates information, yielding structured meanings.

Of course, unification-based composition is only possible if the objects of composition are sufficiently decomposed. Thus, the hallmark of frame semantics is **composition based on decomposition**. In most cases, decomposition is by no means trivial, but often a moderate level suffices because unification of two frames will not require full decomposition of either.

Unification. Truth-functional semantics has essentially two mechanisms of composition: argument saturation and conjunction. Frame semantics has only one – unification – that covers both, and more, such as composition by means of a bridging frame. Unification is guided and restricted by the condition that the nodes to be unified be of compatible types. A simple example would be the interpretation of *red pencil*. The frame for *pencil* is roughly like the one in Figure 2; the frame for the color adjective is analogous to the frame for *cheap* in Figure 3 with the attribute PRICE replaced by COLOR and the type of the value node specified as red. The combination *red pencil* will saturate the argument node of the adjective frame by unifying it with a node of appropriate type, visible object, in the pencil frame. The frame contains three elements that satisfy this type condition: the coating of the casing,

[17] See Schulzek (2017: Ch. 5) for a comprehensive investigation.

the casing itself, and the pigment of the core. Unification is possible with each of them; we obtain three equally legitimate, though not equally likely, senses of the combination.

Indeterminacy. The *red pencil* example shows that composition based on unification is not always deterministic. This is obviously adequate in cases where there are several outcomes of composition possible, while the expressions combined are not lexically ambiguous, nor is the construction ambiguous. Rather the ambiguity is a matter of the compositional process itself. This type of ambiguity is frequent with modification.

The unification approach is able to deal with **sub-compositionality**, which constitutes a notorious problem for traditional formal semantics (Löbner 2012). Against the standard background assumption of a homomorphism between syntactic and semantic operations, a syntactic construction is sub-compositional if it requires different composition rules for semantic subclasses of components. Frame unification allows the modeling of sub-compositionality because unification can draw on the frame content of the meanings combined. Several frame studies deal with sub-compositionality, for example the work on *steigen* 'rise' and sound emission verbs mentioned at the end of §3.1 as well as Balogh & Osswald (2020).

Structured meanings. Unification conflates the information contained in the frames unified and thereby accumulates information. From the very outset at the lexical level, meanings in this approach are structured, and unification preserves all information, and its structure, in the resulting frame. Thus, the frame approach offers a solution to a core problem for truth-conditional composition (King 2019).

When the meaning of a complex expression is composed by unification, the conditions in the unified frames interact: each of the frames becomes context to the others. Therefore, any composition by frame unification is what Pustejovsky calls **co-composition**: the close interaction of the meanings of the participants of composition (Pustejovsky 2012).

While the output of composition is structured meanings, **truth conditions** and logical relations do not get lost: Applying (2) above, any frame can be described in a simple first-order predicate logic language with a model based on the underlying frame ontology (Löbner 2017: S. 2.3 for a formal semantics for frame structures). Logical entailment is frame subsumption. Very importantly, in the frame-semantic approach, we can have different propositions with equal truth-conditions.

Many D-frame analyses have tackled modification, a subject where formal semantics approaches often have difficulties because of the lack of appropriate models of decomposition and of flexibility of the composition rules. The closer the composition, it appears, the more intimate is the conceptual interaction, requiring for deep decomposition. The frame studies on modification have concentrated on adjectives and adverbs, including cases such as the following:

- German *spielerisch schlagen* 'hit playfully' (Goldschmidt et al. 2017, Goldschmidt 2018),
- *smell bad, taste old* (Petersen & Gamerschlag 2014),
- German *sehr dröhnen* 'drone a lot' (Fleischhauer et al. 2019),
- German *sorgfältig* 'carefully', *vorsichtig* 'cautiously' (Gabrovska 2019),
- *clean manually* (Anderson 2019),
- depictives: *eat the steak raw/nude* (Burkhardt et al. 2017).

4.2. From utterance to utterance meaning

Figure 6 displays an attempt at the full picture of utterance meaning, i.e. the meaning of an utterance in an utterance context. It contains four frames which are connected by cross-frame attributes.

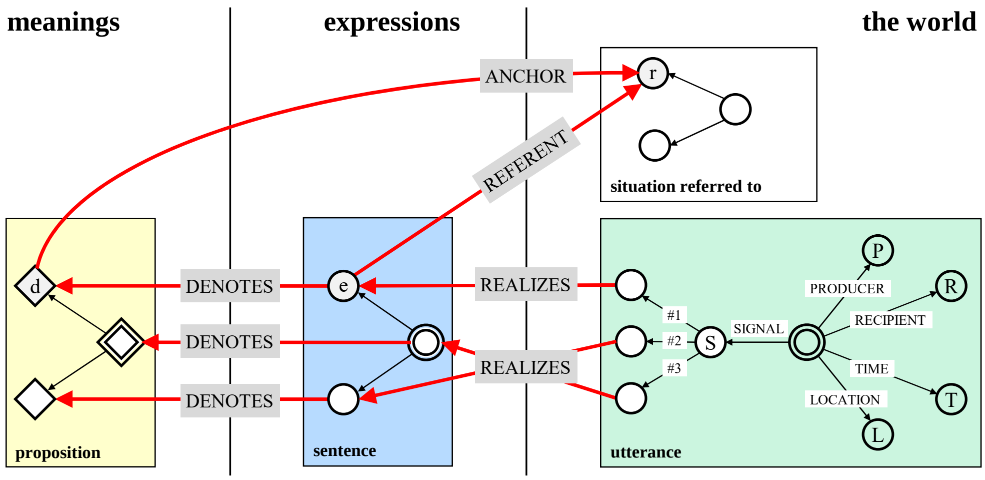

Figure 6
Utterance meaning

Utterance. According to the utterance frame, at time T and location L, P produces a signal S received by R. Let us assume that the signal is a string of three units which are the values of the attributes #1, #2 and #3; let us further assume that we have a SOV language, #1 and #2 are NPs and #3 is a verb. The utterance event is part of the world (as it is represented in the mind of the interpreting party).

Sentence. For the sake of simplicity let the sentence frame be a dependency structure with the verb the main node and the other nodes subject and object; #1 realizes the subject, #2 the object, and #3 the verb. REALIZES is a well-defined attribute that maps elements of the utterance frame on elements of the sentence frame. The sentence belongs to the realm of expressions.

Proposition. The elements of the sentence frame are mapped to the elements of a proposition frame by assigning each element its lexical denotation via the attribute DENOTES (or DENOTATION). Composition integrates the three denotations into one frame, in this case with a structure parallel (homomorphic) to that of the sentence frame. The three denotations are marked with diamond nodes for referentiality. The proposition belongs to the realm of meanings.

Situation referred to. In a given utterance context, the interpreting party will try to anchor the referential elements of the proposition frame to elements in their world frame system. This is indicated here only for the case of node d in the proposition frame, say, the subject argument. The attribute ANCHOR assigns to a referential node in the proposition frame some element r in the world. This is the **referent** of node e in the sentence frame: the referent of a sentence element is the anchor of its denotation. The elements e, d, and r span a version of the classic semiotic triangle. Node r is part of the frame for the situation referred to, which contains anchors for all referential nodes in the proposition frame. The attributes in the situation frame are the same as in the proposition frame, but the nodes will carry more information as the situation frame is situated in the world. Thus, the situation frame is informationally subsumed by the proposition frame. It is realistic to assume that in actual language processing, referential anchoring will not be postponed till semantic composition is completed. Rather, anchoring will go hand in hand with composition: the proposition frame will gradually be unified with world knowledge about the referents chosen until it results in the frame for the situation referred to. The overall structure allows the modeling of personal deixis. For example, for the pronoun *I*, the anchor would be the producer of the utterance. In this case, the situation referred to would overlap with the utterance situation.

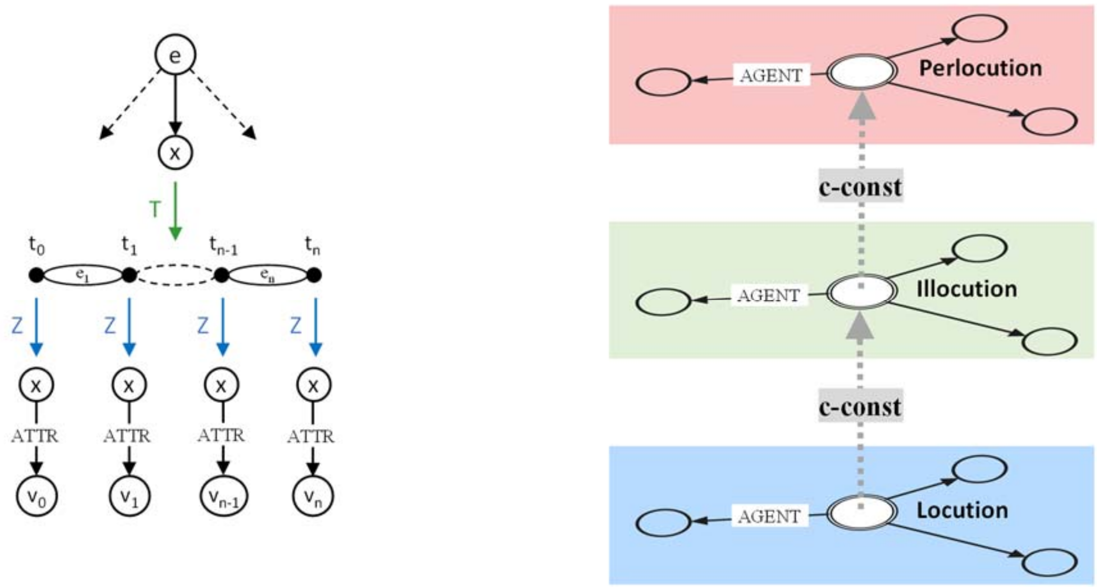

Figure 7

Hyperframes: Dynamic change and Austin’s speech act cascade

In Figure 6, the transitions between elements of different frames are marked with red arrows. They correspond to first-order attributes as they map individuals to individuals. The four frames together with these transitions therefore form one overarching first-order frame. On the other hand, the picture also implicitly displays several interframe, second-order, relations. Some of these have established names such as the relations [EXPRESSION] MEANING between sentence and proposition and UTTERANCE MEANING between sentence and situation referred to.

5. HYPERFRAMES

There are lexical concepts that may require second-order frame structures. I will call them hyperframes. A hyperframe is formed by first-order frames and relations between them. Whether these second-order relations are functional and how they are restricted, is an open, empirical, question. The four frames in Figure 6 can be understood as a hyperframe linked by implicit relations as just indicated. Hyperframes have been developed in D-frame Theory in two fields of application: temporal resolution of dynamic events and multilevel categorization of action.

5.1. Dynamic verbs

The left diagram in Figure 7 displays a schema for a frame representation of dynamic non-punctual verbs of change such as *rise*. This type of analysis was developed in Naumann (2013), Gamerschlag et al. (2014), and Naumann et al. (2018); the schema depicted is based on Naumann et al. (2018, p. 192). Its top level is a case frame for the verb of change. Most such verbs denote a change in the value of one attribute ATTR of one argument x. A temporal so-called zooming-in operation T (Blackburn & de Rijke 1997) links the case frame to a temporal structure of the event which consists of n+1 points in time from the beginning t_0 to the end t_n of the event. The intervals between these points are filled by subevents $e_1, \ldots, e_n$ of the same type as the total event e; they sum up to e. Another zooming-in relation Z assigns each point in time the predication on x in terms of the criterial attribute ATTR.

There are also first-order analyses of dynamic change. One was presented in form of the ‘iku’ frame in Figure 4; however, this analysis applies only to punctual verbs.

5.2. Cascades

The notion 'cascade' is advanced in Löbner (2020). It is inspired by Goldman's (1970) theory of action, which considers actions as things which are, under circumstances, of multiple types simultaneously, thus belonging to as many categories, or, representing tokens of as many types. The action types that simultaneously apply are ordered by a transitive, asymmetric, and irreflexive ordering relation, brought about by what Goldman calls level-generation; Löbner (2020) introduces the notion of "c-const[itution]" (i.e. constitution under circumstances c) for the relation. Level-generation generates act-trees ("cascades") in terms of c-constitution. The crucial relation in a cascade is this: the higher-level actions are done by, or in, executing the lower-level actions. The classic hierarchy of speech acts in Austin (1960) is used here as an example. The lowest-level act in the cascade in Figure 7 is the locutionary act, the production of a verbal utterance with sense and reference. Under circumstances (Austin's "felicity conditions"), the locutionary act c-constitutes an illocutionary act of some type, for example, a promise. The *il*locution is done *in* doing the locution. *By* doing the illocutionary act, the speaker may under the given circumstances c enact a *per*locutionary act of some type, for example 'surprise'. In the frame-theoretical analysis, each level in a cascade is modeled by a first-order action frame. The relation between these is c-constitution; crucially, the frames in a cascade have the same agent and happen at one at the same time, as they happen in one. Since level-generation is transitive and may branch, the relation is not functional.

Cascade theory opens the possibility to account for multi-level categorization of action (also of roles in action). It applies not only in a natural way to abstract "criterion predicates" (Sæbø 2016) such as *break the law* – a type of act that is necessarily implemented by some lower-level, more concrete type of act – but in fact to almost all lexical action verbs. The lowest-possible action level of concrete bodily movements is rarely relevant for describing human action.

Level-generation is a candidate for a basic brain mechanism (Barsalou p.c.); it may underly practical learning of humans as well as animals (see Kalenscher et al. 2020 for rats). The introduction of cascades in lexical verb meanings has far-reaching repercussions for semantic theory (Löbner 2020). First applications have been published in Anderson & Löbner (2018) and Gabrovska (2019).

5.3. Roles

The notion of cascades and c-constitution can be applied beyond actions to roles in actions. By definition, all actions in a cascade are performed by the same agent. However, at a closer look, along with the actions involved, the agent roles, too, differ in type. Being the producer of a locution is not the same as being the producer of the illocution generated, or the producer of a perlocution.[18] Among other things, the agents at these three levels carry different responsibilities. Thus, there is an agent track of cascading parallel to the action track. The levels of agency are related by another c-const relation, which I have called 'c-implementation' in Löbner (2020) in order to set it apart. If, under circumstances, an action a of type A constitutes the action b-of-type-B, then the agent of action a-of-type-A also implements an agent of b-of-type-B. Since the two types of action are logically independent (they need not co-occur), so are the two types of agency.

In Anderson & Löbner (2018), this observation is used for an analysis of the semantic difference between *presidential visit* and *the president's visit*. A presidential visit is always an official visit by the president (or, also, *to* the president), whereas *the president's visit* may be an official visit by the president as the president or else a non-official visit by the president just as a person. An official visit necessarily involves a step of cascading that would be absent in the case of a personal visit. Any

[18] See Löbner (2020) for a deeper discussion of the producer roles in the closely related cascade for writing, with reference to Goffman's (1979) theory of footing.

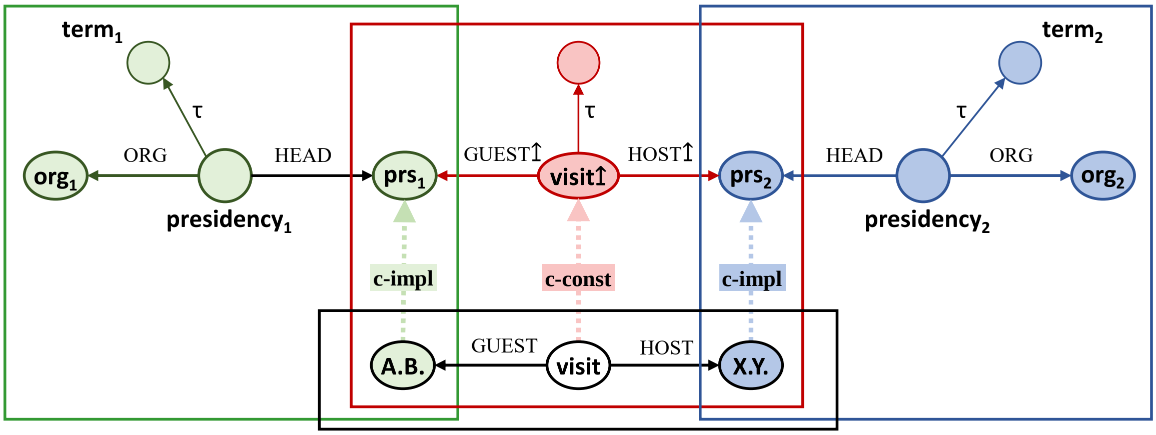

Figure 8
Visiting presidents

official action must be implemented by an appropriate lower-level action (Searle 1995). This lower-level action then, under circumstances, *counts as* the higher level. Let us assume that A. B. and X. Y. are two presidents of comparable institutions, and let us consider the following descriptions of a visit by President A. B.:

(3) a. *President A. B. visits President X. Y.*
b. *President A. B. visits X. Y.*
c. *A. B. visits President X. Y.*
d. *A. B. visits X. Y.*

If it can be assumed that the fact that A. B. and X. Y. are presidents constitutes common ground, each of the four sentences has both readings (Anderson & Löbner 2018). Let me relate these to the model in Figure 8. The green box and its blue counterpart model the situation that somebody is the president of some organization "org" at some time interval. Anderson and Löbner conceive of a presidency as an event of, let's call it, "presiding", roughly meaning 'being president', with two roles, an organization and a head. The head argument of the presidency is the president of the organization. The time interval τ of the presidency is the president's term. The president is c-implemented by a person, the incumbent (INCUMBENT is the inverse relation of c-implementation). In the example, A.B. is the incumbent of the head of org_1; A. B. implements the president of org_1. Thus, a situation of a non-vacant presidency necessarily involves a cascade that contains the level of persons and its projection to the level of office.

Now, if President A. B. spends an official, "presidential", visit to President X. Y., this is an action of Presidents A. B. and X. Y. *as the presidents of* org_1 *and* org_1, hence an action at the office level. The lower-level activity that generates the official visit, of course, involves the incumbents of the offices *as persons*. They have to bring about the official action. In the diagram, the red box marks a presidential visit and its elements. The official visit is represented by the upper-level node labeled vis↥. The vis↥ frame contains the two roles of the official host HOST↥ and the official guest GUEST↥. The action vis↥ is level-generated by some action here labeled 'visit'. Note that this type of action is very different from a normal visit at person level because the actants have to do what the protocol etc. demands. The diagram does not make explicit the condition that the visit temporally overlap with both presidencies.

The analysis applies straightforwardly to the official reading of the first sentence. The green and blue box is activated by the two NPs. Still, the sentence does not necessarily refer to an official visit. In context, the sentence will be disambiguated depending on whether the circumstances as known support or block c-constitution of the office-level visit. If the president titles are omitted, as in (3d) and partly in (3b, c), the content of the green and/or blue presidency box will be recruited from world knowledge for the official-visit reading.

For the personal-visit reading of the two presidents, primarily the black box at the lower level applies. What visitor and host do will differ considerably from an official visit. Above all, it doesn't count as official, and this allows for different activities on both sides and bars others. Still, according to our world knowledge, the presidencies of the two persons *will* matter, at least in terms of modalities such as, say, security measures. Thus, the green and the blue box will be included in the model even in this case.

So much may suffice for a brief impression. The example illustrates that there is potential of the cascade approach beyond the mere level-generation of action. In particular, it promises the possibility to model the ontology of social offices and roles.

6. CONCLUSION

I hope to have demonstrated the rich potential of a D-frame approach to cognitive representations, in particular its application to semantics. Compared to the paradigm of truth-conditional semantics, D-frame theory promises to overcome several severe restrictions. It offers a framework for deep decomposition which provides the basis for a much more detailed account of composition. It models composition as a process of information integration that yields structured meaning. A treatment of some prominent topics of semantics such as quantifiers, modal operators, and propositional attitude constructions is still to be developed, but there are first steps undertaken such as the work on quantification by Kallmeyer & Richter (2014) and Kallmeyer et al. (2017). The D-frame enterprise followed the strategy 'first things first'. For a compositional semantics based on decomposition, the first thing to turn to is lexical meanings of content words.

The approach allows for the modelling of the interaction of linguistic and world knowledge in a uniform model. It is even plausible to assume that all levels of linguistic analysis from phonetics to pragmatics and discourse can be modeled with frames and hyperframes. Most importantly, D-frame theory is based on a concept model developed in experimental psychology, and therefore may have a foot in the door to the understanding of cognitive concept organization. A new paradigm for linguistic research and semantics in particular may be evolving here. There is a lot to do in order to explore the full potential of the approach. The work described here is just the beginning.

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