Report

DFG reference number and title

KI 374/6-1 – Computerlinguistische Modellierung von Funktionalbegriffen und Frames

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1 State of knowledge and goals

According to Barsalou (1992) frames as recursive attribute-value structures form the general format of cognitive concepts. Based on empirical research, Barsalou's focus in developing frame theory was not on providing a formal theory. Our project proposes to both sharpen and generalize his intuitive conceptions by developing an adequate formal model for frames. Our goal is to obtain a better understanding of frames, not only in the special cases they have been used in so far but also on a general basis, and an adequate explanation of cognitive processes. This is necessary for the adoption of frames in various fields of application, such as frame-based semantics, medical diagnosis or frame-based knowledge systems.

2 Results and their significance

We have developed a new approach to frames which rejects the claim that the central node of a frame is its root, which is commonly assumed in standard frame theories. In addition, we have dismissed the artificial distinction between types and attributes in type signatures. These two adaptations enable us to give a classification of acyclic frame graphs that reflects the classification of concepts into sortal, proper relational and functional concepts. In particular, the encouraging fact that the structure of a functional (as well as a proper relational) concept differs fundamentally from that of a sortal concept in our frame theory confirms us that our modifications to standard frame theory can make new insights into concept decomposition available.

a) General frame definition

Since frames for concepts are recursive attribute-value-structures, each attribute of a frame establishes a relation between the objects denoted by the concept and the value of the attribute; for example, the attribute SEX in the frame for *woman* assigns the value **female** to each denoted object. In accordance with the examples in Barsalou (1992) we assume that attributes in frames assign unique values to objects and thus describe functional relations. The values themselves can be complex frames.

We model frames as connected directed graphs with labeled nodes (types), arcs (attributes) and one distinguished central node. Our definitions follow the notational conventions for typed feature structures in Carpenter (1992).

Definition 1: *Given a set* TYPE *of types and a finite set* ATTR *of attributes. A* frame *is a tuple* $F = (Q, \bar{q}, \delta, \theta, \nleftrightarrow)$ *where:*

- Q *is a finite set of nodes,*
- $\bar{q} \in Q$ *is the central node,*
- $\delta:$ ATTR $\times Q \rightarrow Q$ *is the partial* transition function,
- $\theta: Q \rightarrow$ TYPE *is the total* node typing function,
- $\nleftrightarrow \subseteq Q \times Q$ *is the symmetric and anti-reflexive* inequality relation.

Furthermore, the underlying undirected graph (Q, E) *with edge set* $E = \{\{q_1, q_2\} \mid \exists a \in \text{ATTR}: \delta(a, q_1) = q_2\}$ *is connected.*

Contrary to other frame definitions, we do not demand that all nodes of a frame can be reached via directed arcs from its central node. The claim that all nodes of a frame can be reached from its central node is common in most frame theories (cf. Carpenter 1992; Barsalou 1992), because they usually only consider frames for sortal concepts.

The types are ordered in a type hierarchy, which induces a subsumption order on frames: „We think of our types as organizing feature structures into natural classes. […] Thus it is natural to think of the types as being organized in an inheritance hierarchy based on their generality", (Carpenter 1992: 11).

Definition 2: *A* type hierarchy $(\text{TYPE}, õ)$ *is a finite partial ordered set which forms a join semilattice, i.e., for any two types there exists a least upper bound. A type* t_1 *is a* subtype *of a type* t_2 *if* t_1 õ t_2.

b) A classification of Frame graphs

In order to attain a better understanding of the structure of concept frames, which is a necessary prerequisite for an adequate formal frame model, we investigated frames for concepts belonging to different concepts classes (SC, RC, FC) according to Löbner's concept classification (Figure 1). So far, we cannot provide a final satisfying solution for modeling individual concepts in frames.

	non-unique reference	**unique reference**
non-relational	SC: sortal concepts: *person, house, verb, wood*	IC: individual concepts: *Mary, pope, sun*
relational	RC: proper relational concepts: *brother, argument, entrance*	FC: functional concepts: *mother, meaning, distance, spouse*

Figure 1: Löbner's classification of concepts

In the case of acyclic frames we found that these concept classes are reflected by graph-theoretical aspects of the frames modeling the concepts.

A frame is said to be *acyclic* if the underlying directed graph is acyclic, i.e., if it is not possible to find a way along directed arcs leading from a node back to itself. Our experience with the frames constructed in the research group indicates that frames for concepts are generally acyclic. However, there are some rare self-referential concepts like *egoist* or *narcissist* whose frame graphs have to be cyclic.

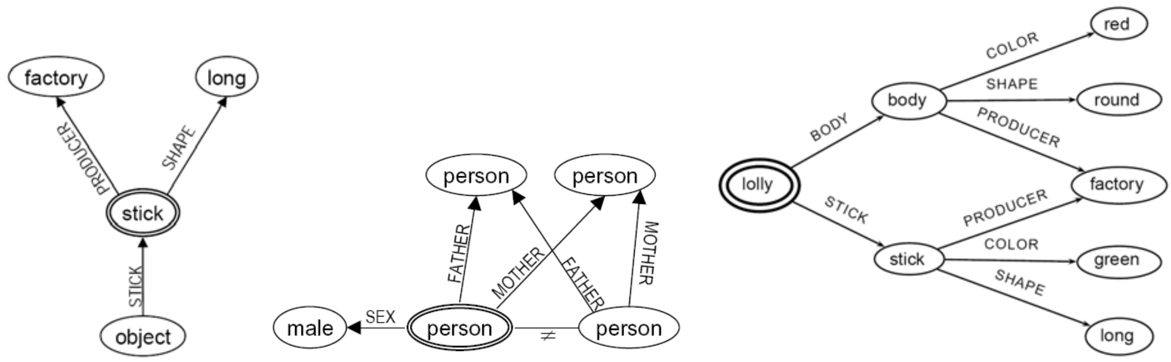


Figure 2: acyclic frames for different concepts (left: *stick [FC]*; middle: *brother [RC]*; right: *lolly [SC]*)

Figure 2 shows three frames belonging to concepts of three different concept classes (the central nodes have been encircled twice). The left frame represents the functional concept *stick*, the frame in the middle corresponds to the proper relational concept *brother*, and the right frame corresponds to the sortal concept *lolly*. The *stick*-frame characterizes a stick by *being the **stick of** an object* (i.e., by a functional relation) and by additional sortal features like *being long* and *being produced in a factory*. Functional concepts differ fundamentally from sortal concepts, since their potential referents are the values of an attribute which is identical with the functional concept. Although the *stick*-frame seems to be a substructure of the frame for the sortal concept *lolly*, the fundamental difference is encoded inherently in the graph structure of the frames: the central node of the functional frame, i.e. the frame for the functional concept *stick*, has an incoming arc, while that of the sortal frame for *lolly* has solely outgoing arcs. Characteristically, both frames have a root (i.e., a node from which all other nodes can be reached along directed paths). It is the incoming arc (labeled by an attribute corresponding to a functional concept) that establishes the functional relation from potential possessors to the referents of the functional concept. The central node in the frame of the sortal concept *lolly* is a source (i.e. a node which has no incoming arcs).

The frame for the proper relational concept *brother* is more complex. It describes a brother as a male person, for whom a second person exists and with whom it shares mother and father. The undirected arc between the two **person**-nodes labeled with ≠ indicates the inequality relation and ensures that the two nodes can never be unified. The peculiarity of this frame is that the two nodes labeled **person** cannot be reached along directed paths from each other and no third node exists, from which both nodes can be reached. Thus, the potential referents of the central **person**-node are characterized by the sortal feature *male* and especially by the existence of referents for the non-central source of type **person**, which represents the possessor argument of the proper relational concept *brother*. The connection between the central node and the node for the possessor argument is indirectly established via the shared values of the FATHER- and MOTHER-attributes. Since the relation between a person and his or her mother (or father) is a many-to-one relation, the *brother*-frame does not set up a functional relation between the possessor argument and the referents of the central node. It is characteristic for a *proper relational frame*, i.e. a frame for a proper relational concept, that it has a node which is a source but from which the central node is not reachable along directed arcs.

The example frames show that the type of concept represented by an acyclic frame is determined by the properties of the central node and the question as to whether or not the frame has a root or a source. A complete classification of acyclic frame graphs with respect to the eight binary features „± has source” (±ES), „± has root” (±ER), „± central node is a source” (±CS), and „± central node is a root” (±CR) is given in Figure 3.

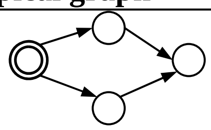
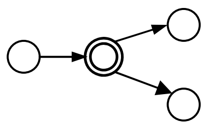
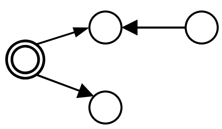
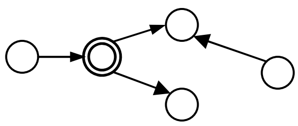
CR	***CS***	***ER***	***ES***	**Typical graph**	***frame class***
+	+	+	+		sortal
–	–	+	+		functional
–	+	–	+		proper relational
–	–	–	+		???

Figure 3: classification of acyclic frame graphs

While the first three frame classes correspond nicely to concept classes, the fourth is special. We assume that frames belonging to this class do not represent lexicalized concepts (for further details see Petersen 2007). From the analysis of the graphs underlying concept frames we derive the following hypothesis:

- The concept classification is reflected by the properties of the frame graphs.
- Relationality: the arguments of relational concepts are modelled in frames as sources that are not identical to the central node.
- Functionality: The functionality of functional concepts is modelled by an incoming arc at the central node.

c) Attributes in frames

Our basic assumption about the structure of frames is that attributes in frames are functional and thus correspond to functional concepts. However, this correspondence does not become evident, if one applies the standard theory of typed feature structures. As Guarino (1992) points out, frame-based knowledge engineering systems as well as feature-structure based linguistic formalisms normally stipulate making a radical choice between attributes and types. Therefore, frames like the ones in Figure 2 are common, in which the rather unspecific value ***stick*** is assigned to the attribute STICK. The parallel naming of the attribute STICK and the type ***stick*** suggests a systematic relationship between the attribute and the type that is not captured by the formalism. While in our research proposal we were very sceptical with respect to Barsalou's claim that everything including attributes can be modelled by frames, our analysis of frames of functional concepts has convinced us that Barsalou's refusal to separate attributes and their values is a compelling argument. But since we are still aware of the problem that modeling attributes in frames as frames bears the risk of an unnecessary double recursive structure (see further down), we aim to posit an alternative solution to the problem.

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As stated above, we presuppose that attributes of frames establish many-to-one, i.e., functional relations between the nodes they are attached to and their values. The question arises as to how attributes and functional concepts are connected. All sample attributes we have used so far (STICK, COLOR, …) correspond to functional concepts. Guarino (1992) distinguishes between the *denotational* and the *relational* interpretation of a relational concept. This distinction can be used to explain how functional concepts can act as concepts and as attributes: Let there be a universe $\mathcal{U}$ and a set of functional concepts $\mathcal{F}$. A functional concept (like any concept) denotes a set of entities:

$$\Delta : \mathcal{F} \to 2^{\mathcal{U}}$$

(e.g., $\Delta(\text{mother}) = \{m \mid m \text{ is the mother of someone}\}$).

A functional concept also has a relational interpretation:

$$\rho : \mathcal{F} \to 2^{\mathcal{U} \times \mathcal{U}}$$

(e.g., $\rho(\text{mother}) = \{(p, m) \mid m \text{ is the mother of } p\}$).

Additionally, the denotational and the relational interpretation of a functional concept have to respect the following *consistency postulate* (Guarino 1992): Any value of a relationally interpreted functional concept is also an instance of the denotation of that concept. E.g., if $(p, m) \in \rho(\text{mother})$, then $m \in \Delta(\text{mother})$. Furthermore, the relational interpretation of a functional concept *f* is a function, i.e. if $(a,b),(a,c) \in \rho(f)$, then $b = c$. These considerations allow us to clarify the ontological status of attributes in frames:

- Attributes are not frames themselves and are therefore unstructured.
- Attributes in frames are relationally interpreted functional concepts.
- Frames decompose concepts into relationally interpreted functional concepts.
- Thus, functional concepts embody the concept type on which categorization is based.

The differentiation between the denotational and the relational interpretation of functional concepts is consistent with Barsalou’s view on attributes: „I define an attribute as a concept that describes an aspect of at least some category members. For example, *color* describes an aspect of *birds*, and *location* describes an aspect of *vacations*. A concept is an attribute only when it describes an aspect of a larger whole. When people consider *color* in isolation (e.g. thinking about their favorite color), it is not an attribute but is simply a concept”, Barsalou (1992: 30).

d) Type signatures and well-typed frames

In the theory of typed feature structures, it is common to enrich the plain type hierarchy by an appropriateness specification. It regulates which attributes are appropriate for feature structures of a special type and restricts the values of the appropriate attributes (Carpenter 1992).[1] We have adapted this technique to restrict the class of admissible frames. However, we have dismissed the artificial distinction between attributes and types in our definition of type signatures: In contrast to the standard definition (Carpenter 1992: 86), the attribute set is merely a subset of the type set. Hence, attributes occur in two different roles: as names of binary functional relations between types and as types themselves (cf. Figure 4).

Definition 7: Given a type hierarchy $(\mathrm{TYPE}, \tilde{o})$ and a set of attributes $\mathrm{ATTR} \subseteq \mathrm{TYPE}$ an appropriateness specification on $(\mathrm{TYPE}, \tilde{o})$ is a partial function $\mathrm{Approp}: \mathrm{ATTR} \times \mathrm{TYPE} \to \mathrm{TYPE}$ such that for each $a \in \mathrm{ATTR}$ the following holds:

- attribute introduction: *There is a type* $\mathrm{Intro}(a) \in \mathrm{TYPE}$ *with:*
    - $\mathrm{Approp}(a, \mathrm{Intro}(a)) = a$ *and*
    - *for every* $t \in \mathrm{TYPE}$ *: if* $\mathrm{Approp}(a,t)$ *is defined, then* $\mathrm{Intro}(a)\ \hat{o}\ t$.
- specification closure: *If* $\mathrm{Approp}(a,s)$ *is defined and* $s\ \hat{o}\ t$, *then* $\mathrm{Approp}(a,t)$

is defined and $\mathrm{Approp}(a,s)\ \hat{o}\ \mathrm{Approp}(a,t)$.

- attribute consistency: *If* $\mathrm{Approp}(a,s) = t$, *then* $a\ \hat{o}\ t$.

A type signature *is a tuple* $(\mathrm{TYPE}, \tilde{o}, \mathrm{ATTR}, \mathrm{Approp})$, *where* $(\mathrm{TYPE}, \tilde{o})$ *is a type hierarchy,* $\mathrm{ATTR} \subseteq \mathrm{TYPE}$ *is a set of attributes, and* $\mathrm{Approp}: \mathrm{ATTR} \times \mathrm{TYPE} \to \mathrm{TYPE}$ *is an appropriateness specification.*

[1] Type signatures can be automatically induced from sets of untyped feature structures, i.e. frames in which the central node is a root and only the maximal paths are typed. With FCAType an implemented system for such inductions is available (Kilbury et. al. 2006; Petersen 2006).

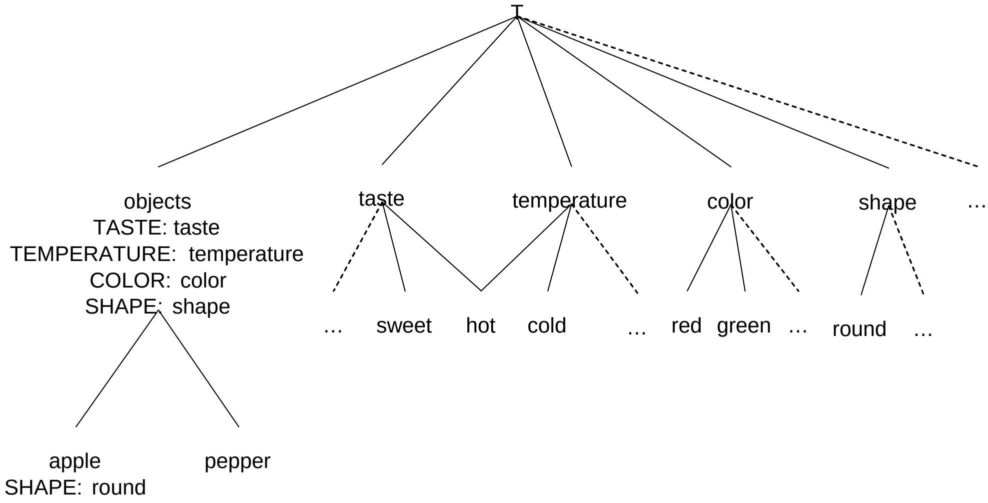

Figure 4: example type signature

The first two conditions on an appropriateness specification are standard in the theory of type signatures (Carpenter 1992), except that we have tightened up the attribute introduction condition. Our claim is that the introductory type of an attribute *a* carries the appropriateness condition $a:a$. Our attribute-consistency condition ensures that Guarino's consistency postulate holds and that Barsalou's view on frames, attributes, and values is modeled appropriately: „At their core, frames contain attribute-value sets. Attributes are concepts that represent aspects of a category's members, and values are subordinate concepts of attributes", (Barsalou 1992: 43). Hence, the possible values of an attribute are subconcepts of the denotationally interpreted functional concept. This is reflected in the type signature by the condition that the possible values of an attribute are restricted to subtypes of the type corresponding to the attribute.

We call a frame *well-typed* with respect to a type signature if all attributes of the frame are licensed by the type signature and if the attribute values are consistent with the appropriateness specification as well. The definition of the appropriateness specification guarantees that every arc in a well-typed frame points to a node that is typed by a subtype of the type corresponding to the attribute labeling the arc. The decomposition of concepts into frames requires that the frames in question are well-typed.

e) Attributes and frames of functional concepts

Due to the recursive structure of frames it is possible to specify the attribute values by frames of any desired complexity. Since the length of attribute paths in frames is not restricted, the frames can fan out in depth as depicted in the upper part of Figure 5. However, Barsalou allows frames to grow in an additional respect: „Within a frame, each attribute may be associated with its own frame of more specific attributes. […] These secondary attributes often have frames as well. […] Even these attributes [of frames of secondary attributes] continue to have frames", Barsalou (1992: 33). The possibility of further specifying attributes as well as their values by additional attributes results in the double recursive and self-similar structure of Barsalou's frames, which is depicted in the lower part of Figure 5.

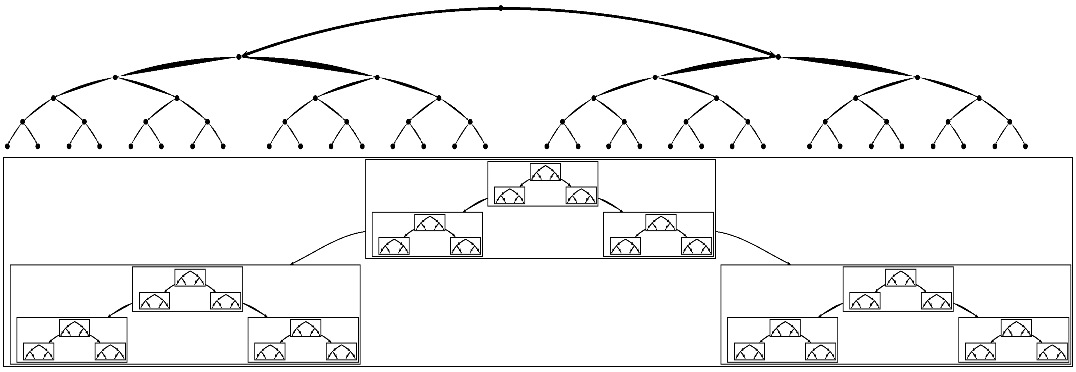

Figure 5: Fanning out of classical frames (top) and Barsalou's self-similar frames (bottom)

Our approach to frames, which reflects the parallelism of the denotational and the relational interpretation of functional concepts in the definition of type signatures, captures Barsalou's idea about frames but avoids the double recursive structure. Since attributes are types at the same time, further attribute-value pairs can specify them; this verifies Barsalou's claim that „frames represent all types of concepts, whether they are free-standing concepts, such as *bird* and *vacation*, or whether they are attributes such as *color* for *bird* and *location* for *vacation*", (Barsalou 1992: 31). However, this further specification can only take place if the attribute is used as a type, i.e., if it labels a frame node, but never when it is used as a functional attribute and labels a frame arc. Our *lolly*-frame in Figure 2 exemplifies this perspective: The attribute *stick* labels an arc as well as a node; however, it is the value of the attribute to which further attribute arcs are attached such that the value constitutes the sortal *stick*-subframe in Figure 6.

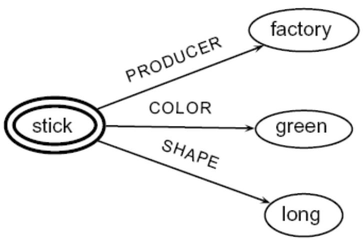

Figure 6: Frame for the sortal reading of *stick*

The attributes PRODUCER, COLOR and SHAPE are attributes of sticks and not of the attribute STICK, since STICK is the partial function that assigns sticks to objects. Note that the *stick*-frame in Figure 6 differs from the *stick*-frame in Figure 2 (left), in that it does not relate the stick to an object to which it is attached. If it is not embedded into a larger object frame (e.g., a *lolly*-frame), it models the sortal reading of *stick* as in the sentence *these days sticks are mostly produced in big factories*. Such context-triggered meaning-shifts from relational concepts to non-relational readings are very common; the frame structures of the concepts help to explain and visualize them. However, we would like to emphasize that the *stick*-frame in Figure 2 (left) must not be confused with the attribute STICK itself: *Stick* is a functional concept, the functional frame of which is given in Figure 2 (left); although it is functional, it denotes – like the sortal *stick*-frame in Figure 6 – sticks. However, in contrast to the sortal frame its denotation is determined by a functional relation from a possessor argument (here the potential referents of the **object**-node). The attribute STICK is the relationally interpreted functional concept *stick* and therefore a function; it is not a frame.

The capacity to give explicit frames for functional concepts that differ fundamentally from frames for sortal readings of these concepts is a novelty. We have made it possible by refining the definition of frames, which no longer demands that the central node be a root of the frame graph.

f) The notion of „minimal upper attributes"

Having outlined the motivation behind our approach to type signatures we will now sketch how it offers a smart solution to problems in grammar engineering occurring when frames are employed as semantic representations. To model how adjectives modify the meaning of a noun it has to be explained that the value **red** in a phrase like *red body* is assigned to the attribute COLOR, while *round body* modifies the value of the attribute SHAPE. An unsatisfactory solution would be to have a single rule for each adjective dimension, i.e. for each attribute. Instead, we propose to introduce the notion of a *minimal upper attribute (MUA)* of a type. An upper attribute of a type is an attribute, which is a supertype of the type with respect to the type hierarchy. Hence, a minimal upper attribute of a type is a minimal element of the set of upper attributes of the type.

According to the type signature in Figure 4, the MUA of **red** is COLOR and the one for **round** is SHAPE. Hence, we can formulate a single rule for all such cases: it states that in a frame representing the meaning of a phrase consisting of an adjective and a noun the type corresponding to the adjective is assigned as a value to the minimal upper attribute of the adjective type. Simplified, the rule can be expressed as follows:

$$\begin{bmatrix}\text{AGR}: & \boxed{1}\\ \text{CONT}: & \boxed{2}\end{bmatrix}_{\mathbf{np}'} \rightarrow \begin{bmatrix}\text{AGR}: & \boxed{1}\\ \text{CONT}: & \boxed{3}\end{bmatrix}_{\mathbf{adj}} \begin{bmatrix}\text{AGR}: & \boxed{1}\\ \text{CONT}: & \boxed{2}\ \begin{bmatrix} MUA(\boxed{3}) : \boxed{3}\end{bmatrix}\end{bmatrix}_{\mathbf{np}'}$$

A rule of this calibre would even capture some interesting cases of ambiguity. Consider the polysemous adjective *hot*, which means either *being very warm* or *being very spicy*. In a type hierarchy the type **hot** could be placed, such that it is a subtype of the attribute type **temperature** as well as of the attribute type **taste** (cf. Figure 4). H**ot** would then have two minimal upper attributes and our rule as applied to the phrase *hot pepper* would result in two frames: one representing a very spicy pepper [TASTE: **hot**] and one representing a very warm pepper [TEMPERATURE: **hot**], which could be part of a dish.

g) A frame-based analysis of synaesthetic metaphors

Our frame model explains new results on the accessibility of synaesthetic metaphors. Beseoglu's & Fleischhauer's (2007) study shows that the accessibility of synaesthetic metaphors expressed as adjective-noun phrases depends heavily on whether the modifying adjective is a quality or a dimension concept. Synaesthetic metaphors in which a dimension concept is used in the source domain (*vivid sound*) are more accessible than synaesthetic metaphors in which a quality concept is used in the source domain (*red sound*).

Interestingly, there is also a noticeable difference between quality and dimension concepts with regard to the MUA of their respective types. While the MUA of quality concepts like *red*, *green* or *blue* is COLOR, the MUA of dimension concepts like *vivid* or *loud* is INTENSITY. Compared to COLOR, INTENSITY is a more general attribute, meaning that it is applicable to all kinds of sense modalities. The adjective *loud* usually connotes *high value of auditory input* and thus modifies the attribute INTENSITY in a sound frame. However, its domain can change when used metaphorically, e.g. when combined with a color concept as in *loud color*, although *loud* still modifies the attribute INTENSITY. While COLOR is specific to concepts belonging to the domain of vision, INTENSITY is neutral with regard to the sense modalities it can be applied to. This can be easily modeled in a type signature containing (among other types) a type **intensity**, which is a supertype of both **color intensity** and **sound intensity**. The former is a scale of color intensities, containing the antonyms **muted** and **vivid** as its extremes. The latter is a scale of sound intensities, containing **quiet** and **loud** as its extremes. Since we only use **intensity** and not **color intensity** or **sound intensity** as an attribute, the MUA of all four types is INTENSITY.

According to our analysis of adjective-noun compounds *vivid sound* would result in a sound frame with the attribute-value pair [INTENSITY: **vivid**]. But this frame is not well-typed, since **vivid** is not a subtype of the type **sound intensity**; the frame exhibits an inadequate value. In order to explain why this metaphor can be grasped anyway, we suppose that the invalid frame is reinterpreted, so that rather than **vivid loud** is used as a value for INTENSITY. Since both **loud** and **vivid** are the maximum of their respective scales, this seems reasonable. Basically, by means of frames the metaphorical expression *vivid sound* is analyzed like the non-metaphorical correlate *vivid red*. They only differ in that the resulting frame of the first one requires an extra reinterpretation step, in order to make it valid with respect to the appropriateness specification.

In contrast to *vivid sound*, we expect *red sound* to fail analysis. Its inaccessibility follows from the fact that the MUA of *red* is COLOR, which is not an attribute of the *sound* frame. The ability to reinterpret *vivid sound* results from the fact that the MUA of *vivid* is an attribute in the *sound* frame. The following hypotheses concerning the analysis of synaesthetic metaphors in adjective-noun compounds can be drawn from our results:

- In general, the same strategies are applied for processing metaphorical and non-metaphorical expressions.
- An expression is mainly inaccessible, if the frame of the compound expression contains inadequate attributes.
- Synaesthetic metaphors with dimension adjectives are more likely to be accessed than those with quality adjectives, since they result in compound frames with adequate attributes but inappropriate values, which can be easily adopted by a reinterpretation step.

However, we are aware of the fact that some empirical findings contradict our hypotheses. An expression like *red sweet* shows higher accessibility results than our account predicts. We expect that *red sweet* is not analyzed like a normal synaesthetic metaphor but is embedded into a more complex *fruit* frame, which maintains that red fruits are more likely to taste sweet than green ones. A formal frame-based account for approaching more general metaphors has still to be developed. Also, more empirical research has to be done to test our hypotheses.

h) Neuronal foundation of frames

In Petersen & Werning 2007 it has been shown that our frame model for the decomposition of concepts is cognitively adequate. It can be straightforwardly extended to account for typicality effects as discussed in project B2. Furthermore, by applying the paradigm of object-related neural synchronization of project B2, a biologically motivated model for the cortical implementation of frames can be developed. For a thorough discussion see the report filed by project B2.

In the process of unifying the results of the two projects (B1 and B2), it appeared that one is compelled to distinguish between reference-shifting attributes (MOTHER) and non-reference-shifting attributes (COLOR), in order to adequately account for the value detectors employed in project B2. For example, one may say that the hue of the color of a cherry is still a property of the cherry and a hue detector may well be directed to the cherry in order to assign a value. However, the sex of the mother of Charly is not a property of Charly, and detecting the value of the sex of the mother of Charly, requires a potential sex detector to be directed to the mother.

It became evident that the distinction between attributes with and without the ability to shift reference can be efficiently implemented in our frame-based grammar engineering environment. In order to analyze a phrase like *bright house* with the single adjective-noun rule explained above, it is necessary to mark the attribute COLOR as not being reference shifting. We have implemented a general constraint that copies every attribute ATTR of the value of an attribute NRS (not reference shifting), attaches it to the node from which the arc labelled NRS starts, and declares the values of the two ATTR arcs as co-referential. Hence, the content of *bright house* would become:

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$$\begin{bmatrix} \text{BRIGHTNESS}: \boxed{1} \\ \text{COLOR}: \quad \begin{bmatrix} \text{BRIGHTNESS}: \boxed{1}\ \text{bright} \end{bmatrix}_{\textbf{color}} \end{bmatrix}_{\textbf{house}}$$

i) Implementation of a frame-based knowledge processing system

During the first project phase, we greatly extended the implementation of the grammar-engineering environment QType in order to support our novel definition of frames. All of our changes are implemented as preprocessors, so that we did not have to interfere with QType internals. First of all, we adapted the external syntax so that our new perspective on attributes and types (cf. section d) could be adequately represented. For example, it is now possible to write „apple :: color, size." instead of „apple :: COLOR:color, SIZE:size.", thus avoiding undesirable redundancies in the type signature.

Apart from that, we implemented the notion of minimal upper attribute, so that grammar engineers can write rules like the adjective-noun rule in section f. Compared to early QType grammars analyzing adjective-noun phrases, this allows for a great amount of simplification by reducing rules for all different kinds of adjective dimensions to one abstract rule fitting them all in a dynamic fashion.

Our last modification deals with the findings regarding reference-shifting attributes discovered by the project B2 (cf. section h). We extended the QType syntax so that grammar engineers may specify which attributes involve reference shifting and which do not. By default, all attributes are considered to be reference shifting, so that users only need to handle non-reference-shifting attributes. E.g., „<< color, brightness." means that COLOR and BRIGHTNESS are non-reference-shifting attributes.

References

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Carpenter (1992): *The Logic of Typed Feature Structures*. Cambridge: Cambride University Press.

Guarino (1992): Concepts, attributes and arbitrary relations: some linguistic and ontological criteria for structuring knowledge bases. In *Data Knowl. Eng., Elsevier Science Publishers B. V., 8*, 249-261.

3 Relation of work schedule to outcome

Although we managed to do justice to the proposed work load all in all, some points turned out to be inadequate for a first project period, since incumbent questions had to be answered first. Gaining a better understanding of the ontological nature of attributes in frames occurred to us as an urgent problem which we had to tackle first, for example. As a result, we had to redefine type signatures. As discussed under point 2, our new definition proved to be fruitful in many respects. A second question which we dealt with successfully, although it was not prominent in the research proposal, is the question of how frames of different concepts differ and whether Löbner's concept classification is reflected in the concept graphs.

We postponed the development of a vector space model for attributes to the second project phase (where the space of attributes is shifted into the centre of interest) and thus considered constraints mainly by means of type signatures. Recently, while working on a frame-based analysis of synaesthetic metaphors (Petersen et. al. 2007), the need to develop an adequate treatment of scalar values in terms of type signatures was stimulated. We hope that we can solve it in a manner that also serves the modelling of constraints like *the older the more valuable*.

The problem of weighted attributes and probabilistic values was tackled, while cooperating with project B2 in order to explain how frames might be implemented in the cortex (Petersen & Werning 2007). Here, probabilistic values and weighted attributes are necessary to account for cognitive typicality effects.

The possibility of employing under-specification and default values in frames is ensured by using typed frames and establishing non-monotonic type signatures. Since our implementation of a frame-based knowledge processing system is an extension of the grammar engineering system Qtype, it is based on non-monotonic type signatures, which offer the advantages of default inheritance without soliciting the disadvantages of default unification (Kilbury et. al. 2006).

Primarily, the long-term goal of establishing a cognitively adequate frame-based semantics has been approached by exploring the possibilities to translate frames into the lambda calculus. Here, it turned out that an appropriate handling of instances and individual concepts is a necessary prerequisite in order to advance a step further in the direction of a frame-based semantics.

3 Cooperation

4.1 within the research unit

We benefitted from the lively discussions in the 2-weekly colloquium held by the research group and the additional lectures held by invited speakers. The exchange initiated by the colloquium led to extra meetings with nearly every project group, which heavily influenced our research. We are unable to specify in detail who we owe which input to our frame approach.

- A1: Clarification of Löbner's classification of concept types that substantially influenced Petersen & Werning 2007.
- A2: Due to postponing the development of a vector space model for attributes, a closer cooperation started only recently while working on the influence of scalar concepts on the accessibility of synaesthetic metaphors (Petersen et. al. 2007).
- A3: valuable exchange and feedback on the formal properties of frames helped us to substantially improve our frame model (cf. Petersen 2007).
- A5: additional weekly exchange in the colloquium on computational linguistics.
- B2: close cooperation that resulted in two published articles (Petersen & Werning 2007, Petersen et. al. 2007) and preparations for further publications.
- B5: the patient description frames of B5 served us as first test frames to clarify the nature of frames. Recently, the problem of formulating appropriate diagnostic frames has been reinvestigated, in order to get a better grip on how to integrate complex constraints into our frame model.

4.2 with external partners

- Nicola Guarino (Trento): ontological status of attributes
- Ontoverse (www.ontoverse.org): Relationship of type signatures and formal ontologies

5 Publications and activities

Refereed publications on scientific congresses

Petersen, W. & Werning, M. (2007): Conceptual Fingerprints: Lexical Decomposition by Means of Frames – a Neuro-cognitive Model. In S. Polovina & R. Hill & U. Priss (eds.): *Conceptual Structures: Knowledge Architectures for Smart Applications (ICCS 2007)*. LNAI 4604, 415-428, Springer.

Petersen, W. (2008): Type Signature Induction with FCAType. In Yahia et al. (eds.): *Proceedings of CLA 2006*. LNAI 4923, 275-280, Springer.

Petersen, W. (2006): FCAType - a System for Type Signature Induction. In S. Yahia & E. Nguifo (eds.): *Proceedings of the 4th International Conference on Concept Lattices and their Applications (CLA'2006)*. Faculté des Sciences de Tunis, Université Centrale, 2006.

Petersen, W. & Kilbury, J. (2005): What feature co-occurrence restrictions have to do with type signatures. In *Proceedings of the Joint Conference on Formal Grammar and Mathematics of Language (FG/MOL-05)*.

Non-refereed publications on scientific congresses

Petersen, Wiebke & Jens Fleischhauer & Hakan Beseoglu & Peter Bücker (2007): *A frame-based analysis of synaesthetic metaphors*. Extended abstract (6 pages) for the conference „A Figure of Speech. Conference on Metaphor.Third International Symposium of Cognition, Logic and Communication". Riga. (A journal article on this subject is in preparation).

Refereed publications in Anthologies

Petersen, W. (2007): Decomposing Concepts with Frames. In J. Skilters & F. Toccafondi & G. Stemberger (eds.): *Complex Cognition and Qualitative Science. The Baltic International Yearbook of Cognition, Logic and Communication*, Vol *2*, (pp. 151-170). University of Latvia.

Kilbury, J. & Wiebke, P. & C. Rumpf (2006): Inheritance-based models of the lexicon. In D. Wunderlich (ed.): *Advances in the Theory of the Lexicon* (pp. 429-477) Berlin: Mouton de Gruyter.

Presentations on scientific congresses (without publication)

Petersen, W. (2007): *Frames for sortal, relational, and functional concepts*. Presentation at CTF 2007. Heinrich-Heine-Universität Düsseldorf.

Petersen, W. (2007): *FCAType - a System for Type Signature Induction*. Poster DGFS Siegen.

Petersen, W. (2006): *Decomposing Concepts with Frames*. Presentation at 2nd International Symposium of Cognition, Logic and Communication; Riga 2006.

Petersen, W. (2006): *Functional Concepts in Frames and Functional Concepts as Frames*. Presentation at 2nd International Conference of the German Cognitive Linguistics Association; München 2006.

Additional presentations (not in a colloquium):

Petersen, W. (2007): *Formale Modellierung von Funktionalbegriffen in Frames.* Presentation at „Tag des wissenschaftlichen Nachwuchses". Düsseldorf, 22 Juni 2007.

Ongoing theses

Martha Grizel Delgado Rodriguez (2008): *Identifikation kontextueller Information in wissenschaftlichen Texten.* Master Thesis (submitted).

Wiebke Petersen (in preparation): *Induktion linguistischer Typsignaturen mit Mitteln der Formalen Begriffsanalyse.* Postdoctoral thesis (Habilitationsschrift).

Additional activities:

- Several student papers on subjects related to the project (e. g. representation of possession in conceptual graphs, frames in OKBC, …).
- Compact Course: Formal Language Theory and the complexity of natural languages. Held by Wiebke Petersen, 6 and 7 December 2006 in Riga.
- Guest lecture by Tanja Hötte: *Ab wann verfügt man über einen Begriff?* 24 January 2007 in Düsseldorf.
- Guest lecture by Nicola Guariono: *Concepts, attributes, and binary relations: representational and ontological issues.* 22 August 2007 at the CTF conference in Düsseldorf.