The Generation and Use of Layer Information in Multilayered Extended Semantic Networks

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Abstract

The paradigm of Multilayered Extended Semantic Networks (MultiNet) is one of the most thoroughly described knowledge representantion systems along the line of semantic networks (Quillian, 1968). The conceptual representation of MultiNet is characterized by embedding its nodes into a multidimensional space of layer attributes. These layer attributes and their values play an important part during the syntactico-semantic analysis of natural language texts and during the inferential answer finding in question answering systems. The paper demonstrates the automatic generation of complex layer information for conceptual nodes and their use in the phase of assimilation of knowledge pieces into a larger knowledge base.

1 Introduction

The paradigm of Multilayered Extended Semantic Networks (abbreviated as MultiNet) lies in the tradition of Semantic Networks (SN), which go back to the work of Quillian (Quillian, 1968) and are especially appropriate for the semantic representation of natural language information. Their main characteristic consists in the fact that concepts are represented as nodes of the SN and relations between them as arcs between these nodes. There can roughly be discerned two lines of development: On the one hand, we have the SN which are closely connected to logic and lean on a model-theoretic extensional semantics (prominent representatives of this line are KL-ONE (Brachman, 1978) and its successors, e. g. (Allgayer and Reddig-Siekmann, 1990), (Peltason, 1991)). On the other hand, there are more cognitively oriented knowledge representation systems like MultiNet introduced in (Helbig, 1997) and comprehensively documented in (Helbig, 2001), which deny the possibility of a fully extensional interpretation of most (if not all) concepts and semantic primitives. Instead of that they prefer an operational or use-theoretic foundation of the semantics of the representational means (Wittgenstein, 1975). MultiNet and its representational means have been designed to fulfill, among others, the following criteria:

- Universality: They are applicable in every domain of application.
- Cognitive adequacy: They put the concept into the center of the semantic representation where every concept has a unique representative. (All other expressional means, like relations between them, have to be considered as constructs of a metalanguage with regard to the concept level.)
- Homogeneity: They can be used to describe the semantics of lexemes as well as the semantics of sentences or texts.
- Interoperability: They are the carriers of all NLP processes (be it lexical search, syntactico-semantic analysis, logical answer finding, or answer generation).

In comparison with other knowledge representation systems, MultiNet (in the first instance) does not allow a concept to play the part of a relation or role (as it is the case with KL-ONE).[1] From the point of view of MultiNet, the logically oriented knowledge representation systems, like DRT (Kamp and Reyle, 1993), are - among other drawbacks - cognitively not adequate because of the lacking concept-centeredness. Furthermore, they are heavily leaning on an extensional interpretation of the logical constructs, which cannot be upheld for many concepts (like "*hill*", "*rich*", "*intention*") or the "natural connectors" (like "*because*", "*if . . . then*", "*if it were . . .*"), which cannot be adequately mapped onto logical junctors.

[1] Even the meaning of words like "*father*" or "*friend*" are primarily represented as nodes in MultiNet (not as relations). Only at a second stage they have an inner relational structure.

One of the important features of MultiNet is the rich inner structure of the semantic representatives of concepts, which is expressed by the embedding of the nodes of the semantic network into a multidimensional space of attributes and their values. The use and processing of these so-called layer attributes is the main topic of this paper.

2 The MultiNet Paradigm

To explain the layer information, we have to deal briefly with the main features of MultiNet (see Figure 1). Concepts are represented in MultiNet by nodes, and relations between concepts are represented as arcs between these nodes. MultiNet has several distinguishing features, the most important of them are:

1. The nodes have a well-defined inner structure which is essentially given by the assignment of the nodes to certain layers of the network specified by the attribute-value structure of special features (see Section 3).

2. Every node is classified according to a predefined conceptual ontology forming a hierarchy of sorts. From that hierarchy, a sort is assigned to every node of the SN (see Appendix A).[2]

3. The arcs can only be labeled by members of a fixed set of relations and functions, which belong to a metalanguage with regard to the conceptual level. The relations are exemplarily described in Appendix B and fully specified by (Helbig, 2001).

4. The whole knowledge about a certain concept C represented by a node N_C is enclosed in a conceptual capsule which is divided into three parts described by the layer feature K-TYPE ("knowledge type") with the values *categ*, *proto*, and *situa*, respectively (see Figure 1):

   Part K: This part comprises all arcs connected to N_C that represent categorical knowledge about C. Knowledge which is marked by the feature value [K-TYPE *categ*] is valid without any exceptions and is connected with monotonic methods of reasoning. Example: "*Every car has a motor*" is categorical knowledge with respect to the concept "car".

   Part D: The prototypical knowledge, which has to be considered as a collection of default assumptions about C. This type of knowledge is characterized by the value [K-TYPE *proto*] and is connected with methods of nonmonotonic reasoning. Example: "*A car (typically) has an air bag.*"

   Part S: Arcs of the SN starting or ending in a node N_C that have no influence on the basic meaning of the corresponding concept C constitute the situational knowledge about C. They indicate the participation of concept C in certain situations. This type of knowledge is characterized by [K-TYPE *situa*]. Example: "*Peter's car had been destroyed in an accident.*"

   For every arc representing a binary relation the layer attribute K-TYPE and its values have to be doubly specified, once with regard to the first argument and once with regard to the second argument.

   Categorical knowledge and prototypical knowledge together form the **immanent knowledge** which – in contrast to the situational knowledge – characterizes a concept inherently. The distinction between immanent and situational knowledge in MultiNet roughly corresponds to the distinction between definitional and assertional knowledge met in other papers (e. g. in (Allgayer and Reddig-Siekmann, 1990)).

5. MultiNet distinguishes an **intensional layer** from a **preextensional layer** where

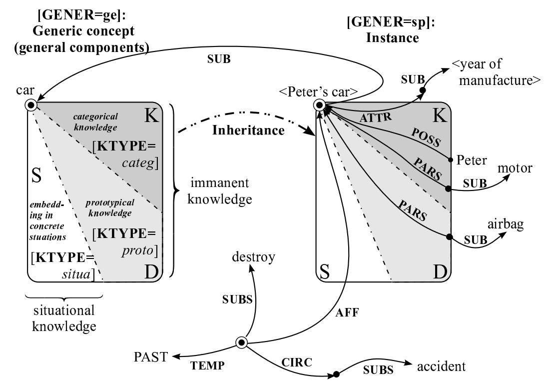

Figure 1: The representation of concepts in MultiNet

[2]It should be remarked that also disjunctions of sorts are allowed as characterizations of conceptual nodes to deal with underspecifications, vagueness, and semantic families (Bierwisch, 1983).

the latter is partially modeling the extension of the first (if the concepts involved can be extensionally interpreted at all).

6. The relations and functions (which are labels of the arcs at the concept level) are themselves nodes at a meta level. They are interconnected by means of axiomatic rules (meaning postulates) which are the foundation for the inference processes working over a MultiNet knowledge base. The signatures (i. e. the domains and value restrictions) of relations and functions are defined by means of the sorts mentioned in point 2 and by means of the layer attributes (see Section 3).

MultiNet has been used and is being used as a meaning representation formalism in several projects (one example is the "Virtual Knowledge Factory" (Knoll et al., 1998)). One important current application is its use as an interlingua for representing the semantic structure of user queries in natural language interfaces to information providers in the Internet and to dedicated databases (Helbig et al., 2000), (Helbig et al., 1996).

3 The Layered Structure of MultiNet

Nodes and arcs of MultiNet are characterized by so-called layer attributes. The layer specifications for arcs are comprised into the attribute K-TYPE and for nodes into another attribute LAY (see Figure 2).

The specifications for the attribute LAY are organized along several dimensions which can itself be described by special attributes having their own values[3]:

FACT: This attribute describes the **facticity** of an entity, i. e. whether it is really existing (value: *real*), not existing (value: *nonreal*), or only hypothetically assumed (value: *hypo*). Examples:
"*Peter* [FACT *real*] *believed that (he was flying)* [FACT *hypo*]."
"*Peter* [FACT *real*] *knew that (he was flying)* [FACT *real*]."

GENER: The **degree of generality** indicates whether a conceptual entity is generic (value: *ge*) or specific (value: *sp*). Examples:

[3]Throughout this paper, we shall concentrate on conceptual objects. For situational concepts, only the layer attributes FACT and GENER are relevant.

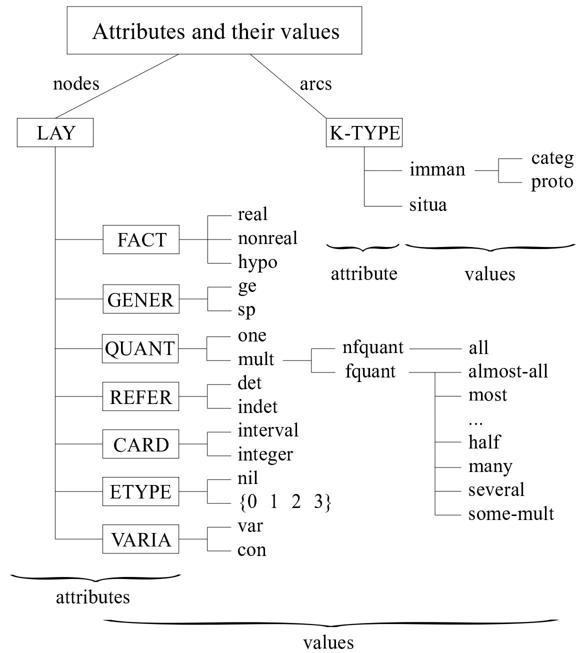

Figure 2: The multidimensional space of layer attributes

"*The crocodile* [GENER *ge*] *is a dangerous animal.*"
"*This crocodile* [GENER *sp*] *is a dangerous animal.*"

QUANT: The intensional **quantification** represents the quantitative aspect of a conceptual entity: whether it is a singleton (value: *one*) or a multitude (value: *mult*). Within the set of values characterizing multitudes we discern between fuzzy quantifiers with value [QUANT *fquant*] (to this group belong "*several*", "*many*", "*most*", etc.) and non-fuzzy quantifiers with value [QUANT *nfquant*] like "*all*".[4]

REFER: This attribute specifies the **determination of reference**, i. e. whether there is a determined object of reference (value: *det*) or not (value: *indet*). This type of characteristic plays an important part in natural language processing in the phase of knowledge assimilation and especially for the resolution of references (see Section 5).
Example: "*The boy* [REFER *det*] *saw a crocodile* [REFER *indet*]."

CARD: The **cardinality** as characterization of a multitude at the preextensional level is the

[4]The natural numbers "*two*", "*three*", ... are characterized by [QUANT *nfquant*] and [CARD 2], [CARD 3], ..., respectively.

pendant of the attribute QUANT at the intensional level. Thus, the intensional characterization of the concept ⟨several students of the class⟩ sometimes can be made more precise by specifying a concrete cardinality (e. g. [CARD 6]) or at least an interval[5] (let us say [CARD (4, 7)]) for the underlying extension on the basis of additional knowledge or a referring expression (e. g. "*three of them . . .*"). Example:
"*(A group of three thieves)* [CARD 1] *stole (many cars)$_i$. Six of* (*them* [CARD (7, _)])$_i$ *were found by the police.*"

ETYPE: This attribute characterizes the **type of extensionality** of an entity with values: *nil* – no extension, 0 – individual which is no set (e. g. ⟨Napoleon I⟩), 1 – entity with a set of elements from type [ETYPE 0] as extension (e. g. ⟨many bears⟩, ⟨the crew⟩), 2 – entity with a set of elements from type [ETYPE 1] as extension (e. g. ⟨three crews⟩), etc.

VARIA: The **variability** finally describes whether an object is conceptually varying (value: *var*) – a so-called parametrized object – or not (value: *con*). Example:
"*This teacher* [VARIA *con*] *loves (every student)* [VARIA *var*]."

The idea of layers is motivated by an analogy to the mathematics of an n-dimensional space. If one fixes a value along one of the axes of an n-dimensional coordinate system, one gets an (n-1)-dimensional hyperplane.

4 Automatic Generation of Layer Information

Layer information for nodes in semantic network representations of natural language sentences can be automatically generated by a parser. Based on lexicalized layer information and grammatical layer knowledge, it produces a set of pairs of layer attributes and values, which can be partially underspecified or hypothetical.

The parsing process for a single sentence is intended to provide a solid base for the treatment of whole texts. When going from the sentence level to the text level, some layer attribute values must be refined or revised because some layer effects can be worked out and fully specified on the text level only.

The generation of layer information can therefore be seen in three steps: The initial information for individual words is provided by the lexicon, the parser adds information based on syntax and semantics of individual sentences, while the final set of layer information is achieved when combining sentence representations by means of text assimilation. Some aspects of the last step are described in Section 5, while the first two steps are described here.

The lexicon contains lexicalized layer values for determiners (articles, demonstrative determiners, quantifiers, etc.), pronouns, nouns, and complement descriptions of verbs. Some partial feature structures for lexical entries are shown in Figure 3, (a)-(g).[6] The attribute values that are

$\begin{bmatrix} \text{QUANT} & \text{mult}^{M} \\ \text{VARIA} & \text{con} \end{bmatrix}$
(a) *die* (the) [pl.]

$\begin{bmatrix} \text{QUANT} & \text{one} \\ \text{REFER} & \text{indet} \\ \text{CARD} & 1 \end{bmatrix}$
(b) *ein* (a/an)

$\begin{bmatrix} \text{QUANT} & \text{all} \\ \text{REFER} & \text{det} \\ \text{VARIA} & \text{con} \end{bmatrix}$
(c) *alle* (all)

$\begin{bmatrix} \text{QUANT} & \text{many}^{M} \end{bmatrix}$
(d) *viele* (many)

$\begin{bmatrix} \text{QUANT} & \text{nfquant} \\ \text{CARD} & 4 \end{bmatrix}$
(e) *vier* (four)

$\begin{bmatrix} \text{CARD} & 1^{M} \\ \text{ETYPE} & 0^{M} \end{bmatrix}$
(f) *Buch* (book)

$\begin{bmatrix} \text{QUANT} & \text{mult}^{M} \\ \text{CARD} & (2,\_)^{M} \\ \text{ETYPE} & 1^{M} \end{bmatrix}$
(g) *Bücher* (books)

$\begin{bmatrix} \text{GENER} & \text{sp}^{P} \\ \text{QUANT} & \text{one} \\ \text{REFER} & \text{indet} \\ \text{CARD} & 1 \\ \text{ETYPE} & 0 \end{bmatrix} = \text{(b)} \sqcup \text{(f)}$
(h) *ein Buch* (a book)

$\begin{bmatrix} \text{QUANT} & \text{many} \\ \text{CARD} & (2,\_)^{M} \\ \text{ETYPE} & 1 \end{bmatrix} = \text{(d)} \sqcup \text{(g)}$
(i)
viele Bücher (many books)

$\begin{bmatrix} \text{GENER} & \text{sp}^{P} \\ \text{QUANT} & \text{nfquant} \\ \text{REFER} & \text{det}^{P} \\ \text{CARD} & 4 \\ \text{ETYPE} & 1 \\ \text{VARIA} & \text{con} \end{bmatrix} = \text{(a)} \sqcup \text{(e)} \sqcup \text{(g)}$
(j) *die vier Bücher* (the four books)

$\begin{bmatrix} \text{GENER} & \text{sp}^{P} \\ \text{QUANT} & \text{all} \\ \text{REFER} & \text{det} \\ \text{CARD} & 4 \\ \text{ETYPE} & 1 \\ \text{VARIA} & \text{con} \end{bmatrix} = \text{(c)} \sqcup \text{(e)} \sqcup \text{(g)}$
(k) *alle vier Bücher* (all four books)

$\bot = \text{(d)} \sqcup \text{(e)}$
(l) (*) *viele vier Bücher* (many four books)

Legend
(*) ungrammatical expression
$\bot$ contradiction (unification failure)
M source: morphological analysis
P source: syntactic analysis (parser)

Figure 3: Layer features for words and NPs

[5]Intervals for the cardinality have to be specified as pairs in the form (⟨lower bound⟩, ⟨upper bound⟩), where in the case of open intervals one of the components can be empty '_'.

[6]As shown in the examples, quantifiers give rise to specific layer features. A quantifier like "*every*" may ad-

refined from more general, disjunctive values by the morphological analysis due to the singular vs. plural distinction are marked with M.

The parser (see (Helbig and Hartrumpf, 1997)) installs a **layer agreement principle** inside NPs by applying a unification operator $\sqcup$ to the elementary constituents of the NP so that the LAY feature of a complex NP will be obtained by this unification operation. Some results produced by the parser are shown in Figure 3, (h)-(l). The last example is ungrammatical. This can be formally explained by the layer agreement principle because the unification of the QUANT values *many* of (c) and *nfquant* of (d) fails (see Figure 2). In some cases, the parser may add default values to the pure unification results; these are marked with P in Figure 3.

To summarize, the layer feature system introduced to represent natural language semantics adequately with intensional and preextensional nodes allows to derive elegantly the layer information of complex NPs from lexicalized and grammaticalized layer information.

5 Layer Information during the Assimilation of Knowledge

The information contained in layer specifications plays an important part during the assimilation of knowledge and especially for resolving references. To explain this process, let us consider the following sentences:

(S1) "*The firm TRAVEL-X bought a new computer.*"

(S2) "*Its hard disk had to be repaired.*"

Without the help of background knowledge the reference of the word "*Its*" can not be properly resolved. First, one has to know that a computer has a hard disk, which is shown together with the semantic structure of sentence (S1) in Figure 4.[7] The fact that the relation (harddisk.1.1 PARS computer.1.1) belongs to the immanent knowledge is represented in the pop-up menu on the right side of Figure 4, where the value *imman* of the attribute K-TYPE is shown for both arguments of this relation. The node initiating a search for an antecedent is the semantic representative c14 for the pronoun "*Its*" of sentence (S2), see Figure 5. It is important that this node bears the attribute value [REFER *det*] (shown in the pop-up menu at the right side of Figure 5), which is starting an inference process for the reference resolution.

To find the antecedent for c14, the assimilation process sets up a query:

(A-Q) (X SUB harddisk.1.1) $\wedge$ (X PARS ??)

meaning "*Which object ?? has a hard disk as its part X?*". X and ?? are variables, where the latter is denoting the focus of the question. Having answered this question by an appropriate inference technique (see (Helbig, 2001), Chapter 13), the nodes found for X and ?? in the background knowledge have to be identified with c15 and c14, respectively (stating that c15 has to be repaired and c15 (substituted for X) is the hard disk of c14).

To answer query (A-Q), further background knowledge is needed. In addition to the fact that a computer has a hard disk (i. e. (harddisk.1.1 PARS computer.1.1)), a piece of knowledge has to be provided that describes the inheritance of the part-whole-relationship in a SUB hierarchy:

(Ax1) (d1 SUB d2) $\wedge$ (d3 PARS d2) $\longrightarrow$
$\exists$d4 [(d4 SUB d3) $\wedge$ (d4 PARS d1)]

Applying this axiom to the knowledge represented in Figure 4 and instantiating the variables d1, d2, and d3 with c13, computer.1.1, and harddisk.1.1, respectively, one can deduce that there exists an object sk13=sk(c13, computer.1.1, harddisk.1.1) which is a hard disk and also a part of c13.[8]

It is easy to see that the assimilation query (A-Q) can be answered on the basis of this knowledge by the substitution σ = {c13/??, sk13/X}. Since on the one hand X and ?? in the assimilation query (A-Q) stand for c15 and c14 in Figure 5, respectively, and on the other hand c13 has been substituted for ?? and the inferred object sk13 has been substituted for X, c15 must finally be identified with sk13 and c14 with c13 in the assimilation process. Putting all results together, one gets the integrated network shown in Figure 6.

ditionally introduce a dependency relation DPND from other network nodes to the quantified node as a lean representation of skolemizations.

[7]The semantic network has been constructed by means of the workbench MultiNet-WR (Gnörlich, 2000) and the natural language analysis system NatLink.

[8]The Skolem term sk13=sk(c13, computer.1.1, harddisk.1.1) indicates that the newly inferred object denoted by this term depends on the nodes given as arguments of the Skolem function sk representing the existentially quantified variable d4 in axiom Ax1.

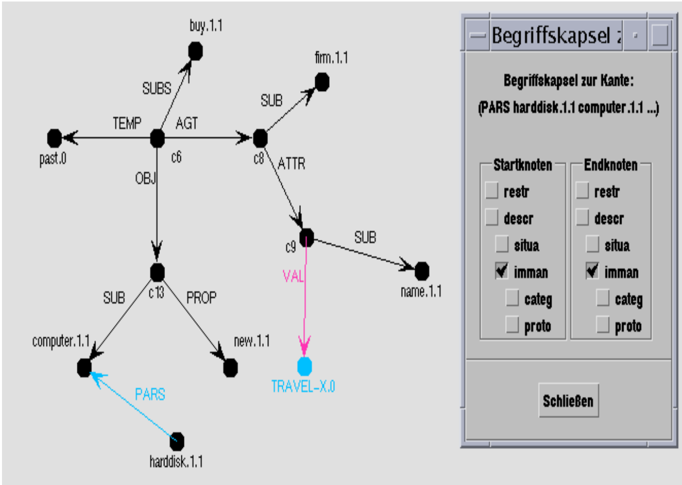

Figure 4: Semantic representation of (S1) with a small piece of background knowledge

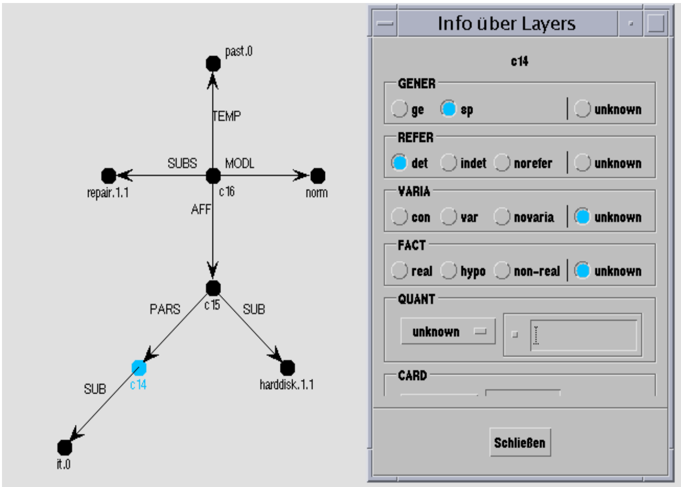

Figure 5: Semantic representation of (S2)

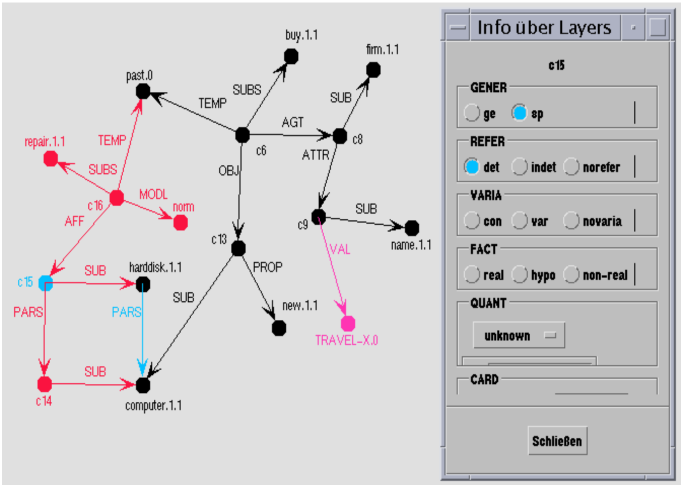

Figure 6: Result of the assimilation of the knowledge parts shown in Figure 4 and 5

The layer information is also important to support the resolution of so-called cumulative references. They are characterized by the fact that the phrase initiating the search for an antecedent has the features of a plural NP (e. g. a pronoun like "*they*"), but there are no collections explicitly represented in the knowledge base accumulated so far. Example:

(S3) "*Peter [QUANT one] met Paul [QUANT one] in the zoo.*"

(S4) "*Together they [REFER det, QUANT mult] went to the aquarium.*"

To resolve the reference of the pronoun "*they*" the assimilation process has to search for a collection C of entities with layer attribute [QUANT *mult*] the members of which are able to go (or formally in terms of MultiNet features[9]: they must have the attribute-value pair [POTAG +], i. e. they must be potential agents). Since there does not exist such an entity in the knowledge base, the assimilation process has to search for single entities with attribute-value pair [POTAG +] and cumulate them into one collection C. Since only the concepts Peter and Paul bear the feature specification [POTAG +], they are the candidates which have to be gathered into one collection C = (*ITMS Peter, Paul). This short description should give an impression how the layer attributes REFER and QUANT are working together in finding antecedents for references to multitudes.

To summarize the role of layer attributes during knowledge assimilation: The attribute REFER with its value [REFER *det*] is initiating the search for antecedents.

The layer attribute K-TYPE, which is relevant to arcs, with the value [K-TYPE *imman*] helps to find the immanent knowledge for closing semantic gaps between sentences.

An entity E characterized by the attributes QUANT having the value [QUANT *mult*] and the attribute REFER with value [REFER *det*] is an indicator for the necessity to gather formerly mentioned single elements in a collection possibly serving as an antecedent for E.

6 Evaluation

One way to evaluate an aspect of a semantic representation formalism (here: the layer features for semantic networks) is to investigate how much applications profit from it.

We have implemented several applications that have access to layer information in semantic networks; one of them is a coreference resolution module for German texts that contains among other components a restricted unifiability test for layer features and achieves competitive recall and precision results. On a corpus with circa 480 coreference links, a significant improvement in F-score from 66% to 72% was observed when the layer component was activated. This result was confirmed by 10-fold cross-validation.

7 Conclusion

The paper has been concentrating on the automatic generation of layer information and the part it is playing in the assimilation process. Another impact of layer information lies in its crucial role for the inferential answer finding in question-answering over MultiNet knowledge bases. Within this context, layer information is relevant to the choice of the adequate inference method (monotonic vs. non-monotonic reasoning) and to the selection of the proper part of knowledge to be included in the answer finding for a certain query class. This topic will be dealt with in a forthcoming paper.

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[9] Semantic features like "potential agent" [POTAG ±], "animate" [ANIMATE ±], "being movable" [MOVABLE ±], and others are used in MultiNet to specify the selectional restrictions of concepts opening valencies.

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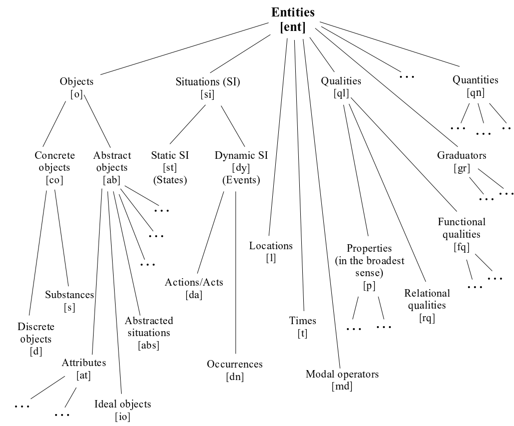
Appendix A: Detail from the Hierarchy of MultiNet Sorts



Appendix B: Short Description of the Relations Used in this Paper

Relation	Signature	Description
AFF	$[si \cup abs] \times [o \cup st]$	C-Role – Affected object
AGT	$[si \cup abs] \times o$	C-Role – Agent
ATTR	$[o \cup l \cup t] \times at$	Specification of an attribute
CIRC	$si \times [ab \cup si]$	Relation between situation and circumstance
MODL	$\tilde{si} \times md$	Relation specifying a restricting modality
OBJ	$si \times [o \cup si]$	C-Role – Neutral object
PARS	$[co \times co] \cup [io \times io] \cup [t \times t] \cup [l \times l]$	Part-whole relationship
POSS	$o \times o$	Relation between possessor and possession
PROP	$o \times p$	Relation between object and property
SUB	$[o \setminus abs] \times [\overline{o} \setminus \overline{abs}]$	Relation of conceptual subordination (for objects)
SUBS	$[si \cup abs] \times [\overline{si} \cup \overline{abs}]$	Relation of conceptual subordination (for situations)
TEMP	$[si \cup t \cup o] \times [t \cup si \cup abs]$	Relation specifying the temporal embedding of a situation
VAL	$\dot{at} \times [o \cup qn \cup p \cup fe \cup t]$	Relation between attribute and its value

Sort symbols can be marked by the following signs: $\overline{o}$ – generic concept with [GENER *ge*]; $\dot{o}$ – individual concept with [GENER *sp*]; $\tilde{o}$ – hypothetical entity with [FACT *hypo*].