Meaning Representation with Multilayered Extended Semantic Networks

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Abstract

Multilayered Extended Semantic Networks (MultiNet) have been developed along the general line of semantic networks (SN) for the semantic representation of large stocks of natural language information. They allow for a very differentiated meaning representation of natural language expressions and an adequate modelling of cognitive structures. MultiNet has been used for the semantic characterization of lexemes in a large computational lexicon and as a semantic interlingua in natural language interfaces and question-answering systems. Apart from the structural information defined by relations and functions over the nodes of the SN (which is a feature common to all SN), MultiNet is characterized by embedding its conceptual nodes into a multidimensional space of layer attributes and differentiating between an intensional and a preextensional level within the knowledge representation itself. The paper gives an overview of the expressional means of MultiNet and their use for representing linguistic knowledge and world knowledge.

Introduction

Multilayered Extended Semantic Networks – the so-called MultiNet Paradigm – are both, a formal language to describe the meaning of natural language expressions and a general knowledge representation formalism. They have been developed along the line of semantic networks starting with the work of Quillian (Quillian 1968) and are fully described in (Helbig 2005). One of the design principles of MultiNet has been the Homogeneity Criterion ((Helbig 2005), p. 4) requiring that a knowledge representation system to be used for natural language processing must be appropriate to describe lexical knowledge as well as world knowledge, linguistic knowledge as well as inferential knowledge. With regard to the computational lexicon HaGenLex, which is one of the largest semantically based lexica (Hartrumpf, Helbig, & Osswald 2003), the expressional means of MultiNet provide the semantic backbone because they are used to specify the meaning structure of lexemes as well as their selectional restrictions. One of the main features of HaGenLex distinguishing it, for instance, from WordNet (Fellbaum 1998) is the fully formal description of the lexemes. Since there is a biunique correspondence between lexicalized concepts and lexemes in our approach, all statements about the semantic representation of concepts in MultiNet have an immediate effect on the characterization of lexemes of HaGenLex. For further details, the reader is kindly referred to the cited book (Helbig 2005), Chapter 12. Here, we shall only concentrate on the basic ideas.

MultiNet networks (or for short: Multinets) are hypergraphs the nodes of which represent concepts, and the arcs between the nodes represent relations and functions establishing a semantic connection between these nodes. In contrast to other network formalisms (e. g. KL-ONE (Brachman & Schmolze 1985), SNePS (Shapiro & Rapaport 1992), the arcs are labelled by relations and functions stemming from a strictly fixed set of representational means. (For examples see Table 2.) These relations and functions can be represented as nodes of a second semantic network at a metalevel which are connected with axioms and inference rules describing the logical properties of these metalevel constructs. One characteristic of MultiNet distinguishing it from simple networks and also from Sowa's Conceptual Structures (Sowa 1984) is the rich inner structure of the nodes. Every node of the network belongs to a sort from a given ontology, and nodes are assigned special semantic features. In addition to that, nodes are embedded in a multidimensional space of layer-attributes and their values.

The Representational Means of MultiNet

Sorts

MultiNet distinguishes the following classes (sorts) of conceptual entities. The class of all nodes (entities) is [*ent*]:

(1) Objects [*o*]: There are two types of objects, **concrete objects** which can be sensually perceived, and such objects for which that is not true, the **abstract objects**.
• **Concrete objects [*co*]**, which are divided into **Substances [*s*]** (Examples: milk, honey, iron) and **Discrete objects [*d*]** (Examples: house, apple)
• **Abstract objects [*ab*]**:
– **Abstract situations [*abs*]** comprising **Abstract dynamic situations [*ad*]** (Examples: race, robbery, integration, movement) and **Abstract static situations [*as*]** (Examples: calmness, equilibrium, awareness, sleep)
– **Attributes [*at*]:** with measurable attributes like height, weight, length, (subsort [*oa*]), and other attributes like form, trait, charm, (subsort [*na*]).
– **Relationships [*re*]:** Examples: analogy, synonymy
– **Ideal objects [*io*]:** Examples: religion, mercy, justice
– **Abstract temporal objects [*ta*]:** Examples: Renaissance, Middle Ages, Easter, holiday, Paleozoic era
– **Modalities [*mo*]:** Examples: probability, necessity, intention, permission, desirability

(2) Situations/States of affairs [*si*]: Situations or states of affairs mirror the constellation of objects in space and time. We distinguish;
• **Static situations (states) [*st*]:** This sort comprises physical states as well as psychic states. Examples: hunger, illness , drought, tiredness
• **Dynamic situations (events) [*dy*]**: These situations are further classified into
– **actions** [*da*] (Examples: work, write, sing, go, sell)
– **happenings** [*dn*] (Examples: rain, decay, shine)

(3) Situational descriptors [*sd*]:
They are seldom lexicalized and often represented by (deictic) adverbial constructs
• **Times [*t*]**, Examples: yesterday, Monday, tomorrow
• **Locations [*l*]**, Examples: here, there
• **Modalities [*md*]:** They express the position of the speaker with regard to the validity of states of affairs or situations.
Examples: probably, impossible, necessary

(4) Qualities [*ql*]: Qualities or specifications of properties can be classified best by an opposing comparison (see Table 1).

Qualities (in general) [*ql*]	
total qualities [*tq*]	associative qualities [*aq*]
• can be predicatively used in natural language; Examples: dead, empty, green, square	• not predicatively usable in natural language; Ex.: chemical, Newtonian, philosophical
gradable qualities [*gq*]	operational qualities [*oq*]
• obtain their full meaning only in connection with other conceptual objects; • predicative use allowed for the corresponding natural language terms; Examples: big, deep, good, expensive	• they describe the position in a sequence or are operationally defined; • they are only defined over generic concepts or pluralities; Examples: fourth, last, next, middle
Relational qualities [*rq*]	
• they have to be interpreted as relations; • they are only usable in connection with pluralities and collective concepts Examples: inverse, equivalent, similar, estranged	

Table 1: Classification of qualities

(5) Quantities [*qn*]: They express the quantitative aspect of concepts.
• **Quantificators [*qf*]:** The quantificators are divided into
– Numerical quantificators [*nu*], Ex.: one, two, . . . five
– Nonnumerical quantificators [*nn*], Ex.: all, many, few
• **Units of measurement [*me*]** Ex.: kg, meter, mile
• **Measurements [*m*]** Ex.: 3 kg, many miles

(6) Graduators [*gr*]: Graduators are used for a more detailed specification of properties and quantities. There are
• **Qualitative graduators [*lg*]:** Ex.: very, rather
• **Quantitative graduators [*ng*]:**, Examples: almost, nearly, approximately

(7) Formal entities [*fe*]: In the context of the lexicon, only strings as elements of sort [*fe*] play a certain role for describing proper names.

Sorts together with semantic features are used in the lexicon to describe the semantic properties of lexemes and their selectional restrictions. The sorts are also important for the definition of the formal properties (especially the signatures) of relations and functions. (See Table 2.)

Layer attributes.

Apart from sorts and features, the concepts of Multinet (and therefore also the lexemes of HaGenLex) are classified according to their assignment to certain conceptual layers which are defined by specific layer attributes and their values. MultiNet distinguishes the following layer attributes (where only the first six are used in the lexicon):[1]
• FACT: The **facticity** of an entity, i. e. whether it is really existing (value *real*, Example: IBM), not existing (value *nonreal*, Example: UFO), or only hypothetically assumed (value *hypo*, Example: string.1.3 - concept from astrophysics). This attribute is still more important to distinguish real facts from hypothetical assumed situations. (The latter typically occur in the meaning representations of conditional sentences.)
• GENER: The **degree of generality** indicates whether a conceptual entity is generic (value *ge*, Example: admiral) or specific (value *sp*, Example: Nelsson).
• QUANT: The intensional aspect of **quantification** specifies whether the concept is a singleton (value *one*) or a multitude (value *mult*) with the subtypes *fquant* and *nfquant* for fuzzy respective non-fuzzy quantifiers. Examples: **a(n)** [QUANT *one*], **several** [QUANT *mult*], **many** [QUANT *fquant*], **all** [QUANT *nfquant*],
• REFER: The **determination of reference**, i. e. whether the concept determines the reference (value *det*) or not (value *indet*). This type of characteristic plays an important part in text processing, especially for reference resolution.
Examples: **this** [REFER *det*] – **a(n)** [REFER *indet*]
• CARD: The **cardinality** characterizes the extensional aspect of a multitude. Such cardinalities are useful, among others, for the disambiguation of coreferences. In the lexicon, they are only used in connection with numerals transferring their cardinality to the representative of a complex noun phrase (when used in such a combination). Examples: **three** [CARD 3], **five boys** [CARD 5]
• ETYPE: The **type of extensionality** of an entity with values: *nil* – no extension, 0 – individual which is no set (e. g. Napoleon), 1 – entity with a set of elements from type [ETYPE 0] as extension (e. g. crew, family) etc.
• VARIA: The **variability** describes whether an object is conceptually varying (value *var*) or not (value *con*). Example: "*This dog* [VARIA *con*] *bites every cat* [VARIA *var*]."

Relations and Functions

MultiNet provides a collection of about 140 relations and functions to describe the interconnections between concepts (i. e. nodes of the semantic network). An overview of the signatures and strongly abbreviated definitions of relations which are typically used for the semantic representation of situations or states of affairs is given in Table 2.

In principle, all of these formal constructs can be used to describe lexical entries (lexemes) too. By means of

[1] It should be noticed that the full potential of the layer attributes and their use can only be recognized in the combination of determiners and quantificators with lexemes designating concepts. This interplay is explained and dealt with in greater detail in (Hartrumpf & Helbig 2002).

Relation	Signature	Short Characteristics
AFF	$[si \cup abs] \times [o \cup si]$	Affected object
AGT	$[si \cup abs] \times o$	Agent of an action
ATTR	$[o \cup l \cup t] \times at$	Specification of an attribute
AVRT	$[dy \cup ad] \times o$	Event averting/turning away from an object
BENF	$[si \cup abs] \times [o \setminus abs]$	Benefactee of a situation
CIRC	$si \times [ab \cup si]$	Relation between situation and circumstance
CAUS	$si' \times si'$	Causality
COND	$\tilde{si} \times \tilde{si}$	Conditional relation
DPND	$ent_{ext} \times ent_{ext}$	Dependency of two concepts
EXP	$[si \cup abs] \times o$	Experiencer of an event
INIT	$[dy \cup ad] \times [o \cup si]$	Relation specifying an initial state
INSTR	$[si \cup abs] \times co$	Instrument of an action
MCONT	$[si \cup o] \times [o \cup si]$	Relation between a mental process and its content
METH	$[si \cup abs] \times [dy \cup ad \cup io]$	Method used in an action
MEXP	$[st \cup abs] \times d$	Mental carrier of a state or process
MODL	$\tilde{si} \times md$	Relation specifying a restricting modality
OBJ	$si \times [o \cup si]$	Neutral object in a situation
OPPOS	$[si \cup o] \times [si \cup o]$	Entity being opposed by a situation
ORNT	$[si \cup abs] \times o$	Orientation towards something
PARS	$[co \times co] \cup [io \times io] \cup [t \times t] \cup [l \times l]$	Part-whole relation
POSS	$o \times o$	Relation between possessor and possession
PROP	$o \times p$	Relation between object and property
PURP	$si \times [o \cup si]$	Purpose of an action
RSLT	$[si \cup abs] \times [o \cup si]$	Result of an event
SCAR	$[st \cup as] \times o$	Carrier of a state
SSPE	$[st \cup as] \times ent$	Entity specifying a state (State specifier)
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

Table 2: Relations for the description of lexical entries
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*].

the attribute NET shown in Figure 3, all lexemes can be embedded into a larger semantic network to describe their meaning. Thus, the NET entry of the lexeme/concept verarbeiten.1.1 of Figure 3 (English meaning: "*to produce something from something*") indicates that the affected object x2 (relation AFF) is a raw material and the result (relation RSLT) is a product. Table 2 shows important relations and functions of MultiNet used in this paper.

These expressional means (shortly subsumed under the term "relations") can be divided into different groups:

- Relations describing situations, among them such relations like AGT (Agent), OBJ (neutral object), AFF (affected object which is changed by an event) etc. They are also used to describe the argument structure (the valencies) of content words.
- Relations characterizing the interconnection between situations, like COND (conditional relation) or CAUS (causality).
- Set relations describing the connection between the extensions of different concepts, like ELMT (element relation), *DIFF (set difference) etc.
- Relations characterizing conceptual objects, like SUB (subordination of concepts), PARS (part-whole-relationship) or LOC (describing the location of an object).
- Relations comparing or opposing concepts. Among these we number:

(X SYNO Y) – X and Y are synonyms, (X ANTO Y) – X and Y are antonyms (this relation comprises the next three relations), (X CNVRS Y) – X and Y are converse, (X COMPL Y) – X and Y are complementary, (X CONTR Y) – X and Y are contrary, (X ASSOC Y) – X and Y are semantically associated with each other.

- Relations expressing a change of sorts, where the third and the fourth letter in the name indicate the sorts from which respective to which the change is carried out. The letters have the following meaning: A – sort [*ab*] (abstract concept), E – [*dy*] (event), P – [*p*] (property), S – [*st*] (state). Thus the following relations hold: (long CHPA length), (hot CHPE (to) heat), (contain CHSA content), (ill CHPS illness).

One great advantage of MultiNet is the fact that the same expressional means used in the lexicon are also used to describe whole knowledge bases by conceptual networks. By that there is a direct way from the lexical representation of word senses, via the results of the syntanctic-semantic analysis of natural language expressions into the knowledge base representing a large stock of natural language information and also to the semantics of question-answering (Hartrumpf 2004). The expressional means of MultiNet are also the carriers of logical inferences and axiomatic rules as shown in the description of the INSTR relation below.

Every relation is described by means of the same schema having the following structure:

relational-definition :: = [⟨name⟩, ⟨algebraic signature⟩, ⟨verbal definition⟩, ⟨mnemonic hint⟩, ⟨question patterns asking for that relation⟩, ⟨explanation consisting of commentaries and axioms⟩]

Table 3 gives a short description of the relation INSTR connecting a specific participant playing the cognitive role of an instrument with an event.

To support an effective work with MultiNets a graphical tool MWR for the knowledge engineer has been developed. It allows for an automatic generation of semantic networks by writing a natural language expression in the input field of MWR (see Figure 1) and calling the syntactic-semantic

C-Role – Instrument	[Deep case relation]

INSTR: $[si \cup abs] \times co$

Definition: The relation (s INSTR o) establishes a connection between an action s and the instrument o which is used to carry out s.

Mnemonics: instrument – (Ge: Instrument)
(s INSTR o) – [s is carried out/sustained with o]

Question pattern: What instrument/tool is used for s?
By means of which ⟨o⟩ [be] s carried out/sustained?
Through what medium ⟨o⟩ [be] ⟨ent⟩ transferred?

Explanation: As it can be seen from the definition, instruments are always concrete objects. To represent the abstract aid by means of which an action is carried out or a state is sustained, the relation METH is also provided in MultiNet. Examples:

- *Peter [drives]* $^{\text{INSTR}_{arg1}}$ *with [his car]* $^{\text{INSTR}_{arg2}}$ *through the town.*
- *Max [draws]* $^{\text{INSTR}_{arg1}}$ *the figure with [the computer]* $^{\text{INSTR}_{arg2}}$.

The simultaneous occurrence of INSTR and METH in one and the same situation is shown by the following example:

- *The results had been obtained [with a PASCAL program]* $^{\text{INSTR}_{arg2}}$ *following the [method of Cooley-Tucker]* $^{\text{METH}_{arg2}}$.

The following connection can be established between INSTR and the relation PURP representing a purpose :

- $(v_1 \text{ SUBS } s) \wedge (v_1 \text{ AGT } k_1) \wedge (v_1 \text{ INSTR } k_2) \rightarrow$
$\exists\, v_2\ (v_2 \text{ SUBS use}) \wedge (v_2 \text{ AGT } k_1) \wedge$
$(v_2 \text{ OBJ } k_2) \wedge (v_2 \text{ PURP } v_1)$

Table 3: Abbreviated definition of the instrument relation

analysis. The result of the semantic interpretation is automatically displayed in graphical form on the main window of MWR.

MWR can also be used by a lexicographer out of his workbench LIA (Hartrumpf, Helbig, & Osswald 2003) to specify the NET attribute of lexical entries. In that, the lexicographer is simply calling the MWR tool by clicking on the NET entry of a given lexeme which is shown and edited by means of LIA. MWR represents this entry as a semantic net, and the network can be graphically manipulated with MWR and stored back into the lexicon in an internal format.

For the sake of illustration, Figure 1 shows the semantic representation of the well-known Donkey-sentence "*Every farmer who owns a donkey beats it.*" automatically created by means of MWR. The values of the layer attributes of "donkey-node" c3 express that c3 is a specific concept [GENER = sp] whose representative at the preextensional level is varying [VARIA = var] in dependency of the extension of the farmer node. (The dependency is expressed by the DPND relation).

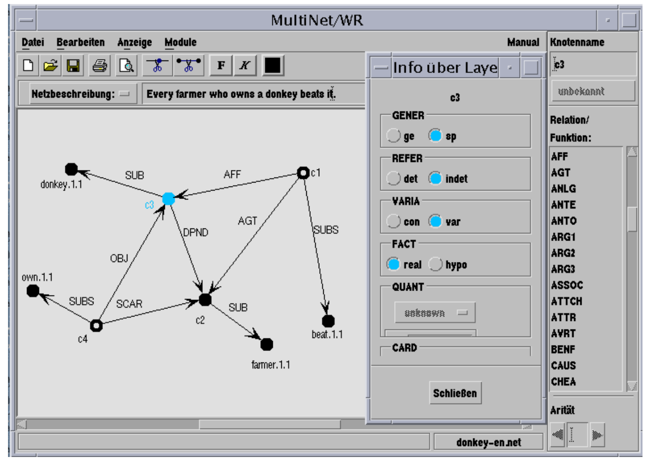

Figure 1: Semantic representation of a Donkey-sentence with layer information of node c3 = ⟨a donkey which is beaten by a farmer⟩

Lexical Knowledge and Semantic features.

On the one hand, the classification of concepts by sorts is not fine-grained enough to describe all semantic restrictions for constituents which are potential fillers for the slots opened by the valencies of lexemes, e. g. there is no MultiNet sort distinguishing the agents admissible to the German word "*essen*" – English "*eat (human)*" from word "*fressen*" – English "*eat (animal)*" (→ [human +] vs [animal +]).

Name	Meaning	Example values +	Example values −
animal	animal	fox	person
animate	living being	tree	stone
artif	artifact	house	tree
axial	object having an axis	pencil	sphere
geogr	geographical object	the Alps	table
human	human being	woman	ape
info	information or carrier of information	book	grass
instit	institution	UNO	apple
instru	typical instrument	hammer	tiger
legper	juridical/natural person	firm	animal
mental	mental concept	pleasure	length
method	method	recursion	book
movable	movable object	car	forest
potag	potential agent	motor	poster
spatial	object with spatial extension	table	idea
thconc	theoretical concept	physics	pleasure

Table 4: Features for the semantic fine-characterization of objects (Hartrumpf, Helbig, & Osswald 2003)

On the other hand, the application of the full repertory of expressional means of MultiNet for describing the selectional restriction of content words – even if principally possible –

would be to unwieldy. For that reason, a compromise has been found in using typical semantic features (or semantic markers) which have over a long time been proven as powerful enough to govern large classes of semantic selections. It must be emphasized, however, that all these features could be omitted and expressed by concepts and relations of MultiNet.
The features allow a very fine-grained specification of lexemes to characterize the most important selectional restrictions of verbs, nouns and adjectives. They also warrant an effective syntactic-semantic analysis, which should not be overburdened with logical inferences.

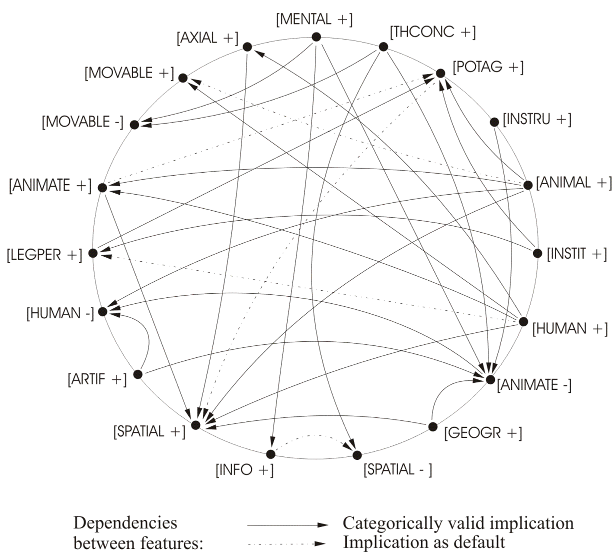

Figure 2: Selected Dependencies between the values of typical semantic features

As it can easily be seen, the values of the semantic features for a certain lexeme are not independent of each other. Figure 2 shows some of the most important dependencies which can be used in the inheritance based lexicon as well as during syntactic-semantic analysis.

Encapsulation of Partial Networks

It is important in a knowledge base to distinguish that part of knowledge which is defining the meaning of a concept (*definitional knowledge*) from that part where the concept in question is only mentioned (*assertional knowledge*). This distinction can also be met in other formalisms as for instance in SB-ONE (Allgayer & Reddig-Siekmann 1990). In MultiNet the definitional knowledge characterizing a concept C is comprised in a concept capsule attached to the semantic representative of C. In Figure 4 the capsule (which is drawn as a box) in the upper part characterizes the generic concept van while the capsule in the lower part describes the individual concept ⟨a van built by Ford⟩.

This distinction is important during inferential answer finding to select that knowledge which provides the basis for answering questions like "*What is a van?*". Orthogonally to this classification there is another partition of knowledge in MultiNet discerning between *categorical knowledge* with regard to a concept (marked by K in the graphical representation of Figure 4), *prototypical or default knowledge* (marked by D) and *situational knowledge* (marked by S).

```
MORPH   [BASE "verarbeiten"
         STEM "verarbeit"]
SYN     [v-syn
         V-TYPE      main
         PERF-AUX    haben
         SEP-PREFIX  ""
         V-CONTROL   nocontr]
SEMSEL  [SEM     [sem
                  ENTITY [nonment-action]
                  NET    ((SUB X2 ROHMATERIAL.1.1)
                          (SUB X3 PRODUKT.1.1))
                  LAY    si-lay
                  MOLEC  0]
         C-ID    "verarbeiten.1.1"
         DOMAIN  general
         SELECT  < [REL   {AGT x1}
                    OBLIG +
                    SEL   [SYN    [np-syn
                                   CAT np
                                   AGR [CASE nom]]
                           SEMSEL [SEM [sem
                                        ENTITY [object
                                                POTAG +]]]]],
                   [REL   {AFF x2}
                    OBLIG +
                    SEL   [SYN    [np-syn
                                   CAT np
                                   AGR [CASE acc]]
                           SEMSEL [SEM [sem
                                        ENTITY [con-object]]]]],
                   [REL   {RSLT x3}
                    OBLIG +
                    SEL   [SYN [pp-syn
                                P-POS   pre
                                P-CASE  dat
                                P-FORM  "zu"]]] >
         COMPAT-R {dur fin goal instr meth purp sourc strt}
         COMPAT-H nosem
         EXAMPLE  "(Der Tischler) (verarbeitet) (Holz) (zu einem Schrank)."
         ENTAIL   "x1 verarbeitet x2 zu x3: x1 stellt x3 her: x3 besteht aus x2"]
ORIGIN  "DS 1999-11-22"
```

Figure 3: Formal characterization of the German lexeme verarbeiten.1.1 which corresponds to the reading "*to process something*"

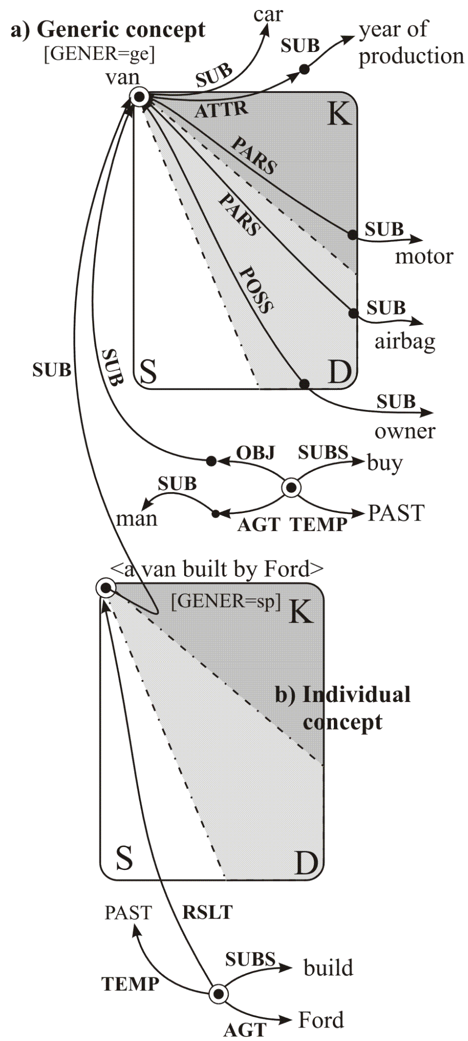

Figure 4: Partial networks (concept capsules) defining the extent of meaning of two different concepts

Taking the concept van from Figure 4 we have the following distinction: That a van is a car having a motor and a year of production is categorical knowledge. Having an airbag as a part is assumed as default knowledge for a van. Default knowledge and categorical knowledge together constitute that knowledge which is immanently connected with a concept. Categorical knowledge is connected with monotonic reasoning, while default knowledge has to be treated with methods of non-monotonic reasoning. As mentioned already, there is a third kind of knowledge, the so-called situational knowledge. In Figure 4 the information that "*Ford built a van*" is classified as situational knowledge with regard to this special van. Often (but not always) situational knowledge and assertional knowledge coincide. However, the lower capsule shows that the situational knowledge that a certain van has been produced by Ford must be classified as definitional knowledge with regard to this special concept node. The role of this cross-classification into different knowledge types for the answering of special question classes (especially for different types of so-called "*Essay questions*") is explained more detailed in (Glöckner & Helbig 2005).

Conclusion

MultiNet is one of the most comprehensively described knowledge representation paradigms which have been used in practically relevant NLP applications.[2] It is also the basic formalism for the description of lexemes/concepts in one of the largest semantically oriented and formally described computational lexica. MultiNet is distinguished from other semantic network formalisms with regard to its expressional means by a multilayered structure, a rich inner structure of nodes and encapsulation of partial networks to build complex concept descriptions. The MultiNet formalism provides also the target language for a natural language interpreter which has been used (and still is in use) for the semantic annotation of large NL corpora with millions of sentences and for question-answering over these corpora.

References

Allgayer, J., and Reddig-Siekmann, C. 1990. What KL-ONE lookalikes need to cope with natural language. In Bläsius, K. H.; Hedtstück, U.; and Rollinger, C.-R., eds., *Sorts and Types in Artificial Intelligence*. Berlin, Germany: Springer. 240–285.

Brachman, R. J., and Schmolze, J. G. 1985. An overview of the KL-ONE knowledge representation system. *Cognitive Science* 9(2):171–216.

Fellbaum, C., ed. 1998. *Wordnet. An Electronic Lexical Database*. Cambridge, Massachusetts: MIT Press.

Glöckner, I., and Helbig, H. 2005. Wissensrepräsentation und Antwortfindung mit Mehrschichtigen Erweiterten Semantischen Netzen. *Künstliche Intelligenz*. To appear.

Hartrumpf, S., and Helbig, H. 2002. The generation and use of layer information in multilayered extended semantic networks. In Sojka, P.; Kopeček, I.; and Pala, K., eds., *Proceedings of the 5th International Conference on Text, Speech and Dialogue (TSD 2002)*, Lecture Notes in Artificial Intelligence LNCS/LNAI 2448, 89–98.

Hartrumpf, S.; Helbig, H.; and Osswald, R. 2003. The semantically based computer lexicon HaGenLex – Structure and technological environment. *Traitement automatique des langues* 44(2):81–105.

Hartrumpf, S. 2004. Question answering using sentence parsing and semantic network matching. In Peters, C., and Borri, F., eds., *Results of the CLEF 2004 Cross-Language System Evaluation Campaign, Working Notes for the CLEF 2004 Workshop*, 385–392.

Helbig, H. 2005. *Knowledge Representation and the Semantics of Natural Language*. Berlin, Heidelberg: Springer. To appear.

Quillian, M. R. 1968. Semantic memory. In Minsky, M., ed., *Semantic Information Processing*. Cambridge, Massachusetts: MIT Press. 227–270.

Shapiro, S. C., and Rapaport, W. J. 1992. The SNePS family. In Lehmann, F., ed., *Semantic Networks in Artificial Intelligence*. Oxford: Pergamon Press. 243–275.

Sowa, J. F. 1984. *Conceptual Structures. Information Processing in Mind and Machine*. The System Programming Series. Reading, Massachusetts: Addison-Wesley.

[2] http://pi7.fernuni-hagen.de/research/research.html#Projects