Multilayered Extended Semantic Networks as a Language for Meaning Representation in NLP Systems

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Abstract

Multilayered Extended Semantic Networks (abbreviated: MultiNet) are one of the few knowledge representation paradigms along the line of Semantic Networks (abbreviated: SN) with a comprehensive, systematic, and publicly available documentation. In contrast to logically oriented meaning representation systems with their extensional interpretation, MultiNet is based on a use-theoretic operational semantics. MultiNet is distinguished from the afore-mentioned systems by fulfilling the criteria of homogeneity and cognitive adequacy. The paper describes the main features of MultiNet and the standard repertoire of representational means provided by this system. Besides of the structural information, which is manifested in the relational and functional connections between nodes of the semantic network, the conceptual representatives of MultiNet are characterized by embedding the nodes of the network into a multidimensional space of layer attributes. To warrant cognitive adequacy and universality of the knowledge representation system, every node of the SN uniquely represents a concept, while the relations between them have to be expressed by a predefined set of about 110 semantic primitive relations and functions. The knowledge representation language MultiNet has been used as an interface in several natural language processing systems. It is also suitable as an interlingua for machine translation systems.

1 Introduction

Prior to the design of a knowledge representation system (abbreviated: KRS) which is to be broadly acceptable, one should have a collection of criteria such a KRS must fulfill. This claim is especially important, if the planned KRS is to be used as an interlingua for the meaning representation of natural language information, which can be employed in different NLP systems. Unfortunately, there is no general consensus with regard to the criteria such a system has to meet. Nevertheless, designing the knowledge representation language of Multilayered Extended Semantic Networks (the so-called MultiNet paradigm (Helbig, 2001)), which has been developed along the line of tradition of the well known Semantic Networks going back to the work of Quillian (Quillian, 1968), we started with a predefined set of criteria. To the best of our knowledge, there is no KRS satisfying these criteria in every respect. But – as we believe – MultiNet comes very close to these requirements. The most important of the above mentioned criteria to be met by the representational means of a KRS or of an interlingua

are the following:
Global requirements

- Universality: The representational means are applicable in every domain (i.e. they are not adapted to a special field of discourse). They have also to be independent of a specific natural language.

- Cognitive adequacy: They put the concept into the center of the semantic representation where every concept has a unique representative. All other expressional means, especially the 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, syntactic-semantic analysis, logical answer finding, natural language generation, or the translation into a foreign language).

- Automatability: They must allow for an automatic (or at least computer assisted) knowledge acquisition.

- Practicability: They should be technically treatable without inappropriate effort and also be easily communicable in a certain community or in a team.

Internal structural requirements

- Completeness: There should be no meaning of a natural language construct which can not be represented properly.

- Optimal granularity: On the one hand, the system should be fine-grained enough to allow for the representation of all essential differences in meaning. On the other hand, the system need not mirror the tiniest nuances of meaning, otherwise it will not be manageable on a computer.

- Consistency: Contradictions must not be derivable from the basic definitions of the representational means.

- Stratification: It must be possible to represent the different semantic aspects (like intensional vs. extensional aspects, or immanent vs. situational aspects) in different layers of the KRS.

- Local interpretability: Each elementary construct (especially nodes and links in a network representation) must have its own context-independent interpretation and must be connected with special logical devices (inference rules, inheritance principles, etc.)

MultiNet is distinguished from other semantic network representations like KL-ONE (Brachman, 1978) and its successors (e.g. (Allgayer and Reddig, 1990), (Peltason, 1991)) as well as from logically oriented knowledge representations like DRT (Kamp and Reyle, 1993) or Description Logic (Baader et al., 1998) by the criteria of cognitive adequacy and homogeneity. All these KRS have a model-theoretic extensional foundation which can not be upheld for many concepts (like “intension”, “charm”) or even for common properties (like “tall”, “happy”). It is not known that the above cited systems have been used for the semantic description of large stocks of lexical information, while MultiNet has been the base for the full syntactic-semantic description of more then 14000 lexemes ((Schulz, 1999), this work is being continued). From all semantic network paradigms, MultiNet comes closest to SNePS (Shapiro, 1999) but is essentially distinguished from this system by its multilayered structure and the encapsulation of concepts.

2 The Main Characteristic of the MultiNet Paradigm

As with other semantic networks, concepts are represented in MultiNet by nodes, and relations between concepts are represented as arcs between these nodes (see Figure 1). Aside of that, MultiNet has several characteristic features, the most important of them are:

1. Every node is classified according to a predefined conceptual ontology forming a hier-

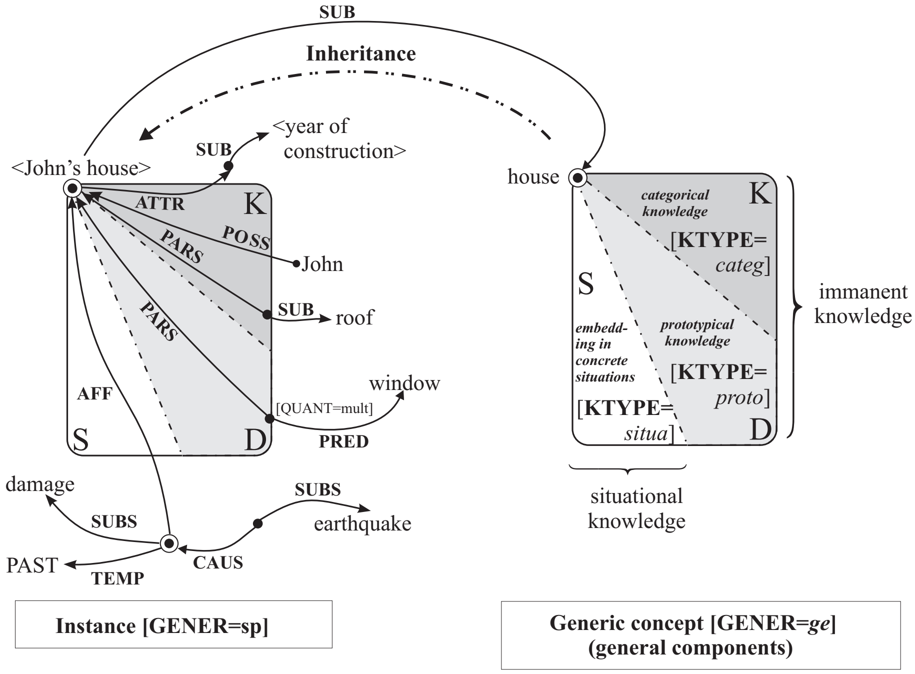

Figure 1: The representation of concepts in MultiNet

archy of sorts (see Figure 2). From that hierarchy, a sort is assigned to every node of the SN.

2. 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 5).

3. The arcs may 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 and functions are exemplarily described in Section 4 and summarized in Appendix A (their full specification can be found in Part II of (Helbig, 2001)).

4. MultiNet distinguishes an **intensional layer** from a **preextensional layer** where the latter is modelling the extension of the first (if the concepts involved can be extensionally interpreted at all). It should be emphasized that certain aspects of the extensional meaning of concepts have to be modeled in the knowledge representation itself (not entirely outside of it as it is the case with logically oriented KRS) to deal properly with such expressions like "*the one … and the others*", "*three of them*", etc.

5. 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 with the values *categ*, *proto*, and *situa*, respectively (see Figure 1):

   - Component K: This part comprises all arcs connected to N_C which represent categorical knowledge about C. This 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 house has a roof*" is categorical knowledge with respect to the concept "*house*".[1]

[1] It should be remarked that the relation POSS starting

- Component D: This component characterizes 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 non-monotonic reasoning.
  Example: "*A house (typically) has several windows.*"
- Component S: Arcs of the SN starting or ending in a node N_C which 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: "*John's house had been damaged by an earthquake.*"

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, 1990)).

6. The relations and functions (which are labels of the arcs at the concept level) are themselves nodes at a metalevel. 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.

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)). The most important application at the moment 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 local data bases (Helbig et al., 2000), (Helbig et al., 1996). For that purpose, transformation modules have been developed which translate the semantic structure of these queries formulated by means of the MultiNet language into the Internet protocol Z39.50 and into SQL, respectively.

3 Sorts and Features of concepts

The classification of nodes, i.e. of the semantic representatives of concepts, into sorts is an important basis for the definition of the domains and value restrictions of relations and functions establishing the interconnections between nodes in a semantic network (see Section 4). The upper part of the conceptual ontology used in MultiNet is shown in Figure 2. The sorts being characterized by this ontology are not only crucial for the formal definition of the representational means, they are also an important source for the semantic interpretation of natural language constructs (e.g. prepositional phrases). This especially holds for the semantic disambiguation of relations underlying a natural language construct, since not all relations may connect a certain pair of conceptual nodes. This decision is supported by the specification of the signatures of the relations involved in the semantic representation of the natural language construct that has to be interpreted (see Appendix A).

> Example: In the phrase "*The holidays in the spring*", the preposition "*in*" must be interpreted by the temporal relation TEMP (and not for instance by a local relation), since the

from the concept "*John*" on the left-hand side in Figure 1 has to be characterized as categorical with regard to the node "*John's house*". Even if in general the possession of things is changing situationally, a house which is not owned by John can not be characterized as "*John's house*". An individual concept like "*John's house*" generally does not have a default part of knowledge. This can be only the case, if it is inherited from general concepts (in this case from the concept "*house*" from which it is known that a house (typically) has several windows; but there are also storehouses without any windows).

semantic representative of the phrase "*in the spring*" bears the sort t (a temporal interval).

From the point of view of the syntactic-semantic analysis of natural language expressions the sorts described above are not sufficient to specify the selectional restrictions or valencies connected with certain words (especially with verbs). For that we need additional features, like being animated (feature: [ANIM +]), being an artifact (feature: [ARTIF +]), having a distinguished axis (feature: [AXIAL +]), being a geographical object (feature: [GEOGR +]), being movable (feature: [MOVABLE +]), and others. Actually, these features can be described by other expressional means of MultiNet too (like the subordination of concepts or the assignment of properties to objects). However, because of their importance for the description of valencies in a computer lexicon and their prominent role in finding the proper constituents filling the valencies during syntactic-semantic analysis the semantic features have been given a special status. As representational means of the lexicon, they are at the same time marking the interface between lexical knowledge and world knowledge. A complete description of the system of sorts and features connected with MultiNet can be found in (Helbig, 2001). The restrictions imposed by them on the specification of relations and functions or on the valency frames of verbs, nouns, and adjectives are automatically observed in the workbenches for the knowledge engineer and for the computer lexicographer, respectively (see Section 6).

4 Relations and Functions of MultiNet

The formal devices for interlinking the conceptual nodes of a semantic network are relations and functions which are properly described in MultiNet by means of the following characteristic components (for a typical example see Figure 3):

- A short caption with a name as expressive as possible
- The algebraic signature of the relation or function leaning on the MultiNet hierarchy of sorts
- A verbal characterization of the relation or function
- A mnemonic hint supporting the communicability
- Patterns of queries aiming at the relation
- A detailed description showing how to use the relation or function and what logical axioms define the inferential properties of them.

MultiNet provides about 110 semantic primitive relations and functions which can roughly be classified into the following groups:

- Relations and functions of the intensional level. They are used to describe conceptual objects and situations with their inner structure and their relationships to other entities. Typically for the description of objects are the characterization of their material structure (by the part-whole relationship, relation PARS, or by their material origin, relation ORIGM) or their qualitative characterization (by means of properties, relation PROP, or attribute value specifications, relations ATTR, VALR, VAL) and others. It is typical for the description of situations to characterize them by means of the roles the participants in these situations are playing (expressed by deep case relations like agent, relation AGT, or experiencer, relation EXP, etc.) Additionally, they are characterized by their spatio-temporal embedding (by means of local relations, like LOC or DIRCL, or by the temporal relations like TEMP or ANTE). The representational means of the intensional level are briefly described in an overview shown in Appendix A.
- Lexical relations. They describe connections between generic concepts and play an important role in the specification of lexical entries (whence their name). To this group

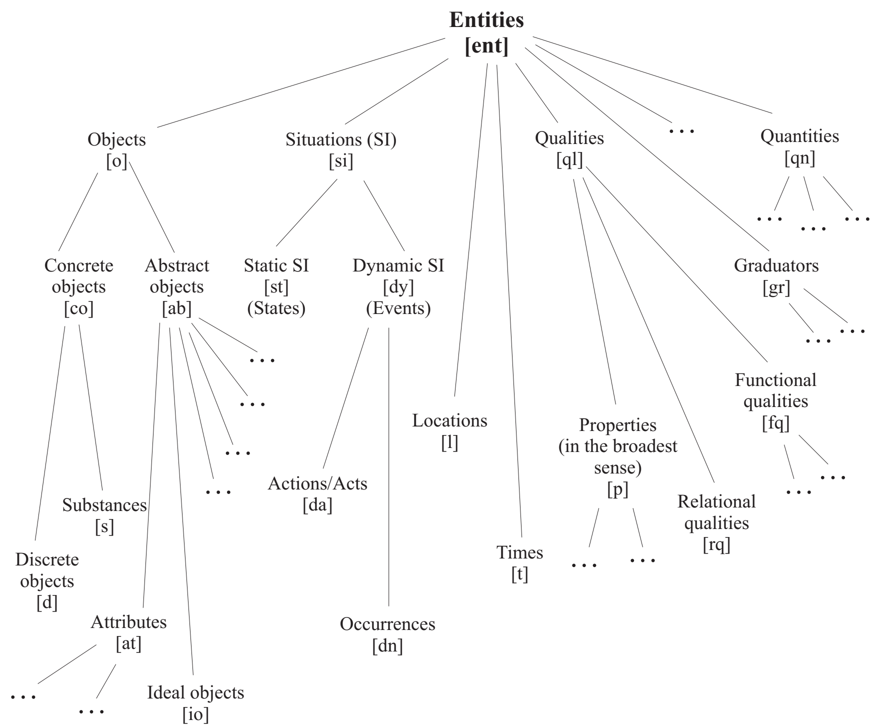

Figure 2: The Upper Part of the Hierarchy of MultiNet Sorts

belong the relations specifying synonyms or antonyms, converse concepts and complementary concepts, etc.). To this group also belong the relations characterizing a change of sorts from one concept to a related concept (like the relation CHEA between an event, e.g. "produce", with [SORT=dy], and an abstract situation, e.g. "production", with [SORT=ab]).

- Relations and functions of the preextensional level. They characterize the necessary modelling of sets and extensional representatives, which have to be included in the knowledge representation itself to deal properly with the meanings of constructs involving sets (like "most of them").

Relations and functions connecting nodes at the conceptual level can themselves be seen as nodes of a metalevel, which are connected by axioms written in the form of predicate calculus expressions (to be more exact, in the form of implications). In that, we discern two types of axioms:

- B-axioms: They connect relations and functions with representatives of natural language concepts. As an example, we give the axiom stating that the part has a weight minor to that of the whole:
  $(k_1 \text{ PARS } k_2) \wedge (k_2 \text{ ATTR } m_2)$
  $\wedge (m_2 \text{ SUB weight}) \wedge (m_2 \text{ VAL } q_2) \longrightarrow$
  $\exists m_1 \, \exists q_1{:}\ [(k_1 \text{ ATTR } m_1) \wedge (m_1 \text{ VAL } q_1)$
  $\wedge (m_1 \text{ SUB weight}) \wedge (q_1 \text{ MIN } q_2)]$

- R-axioms: They connect relations and functions with each other and do not contain natural language concepts. Example:
  Inheritance of the part-whole relationship:
  (d1 SUB d2) ∧ (d3 PARS d2) ⟶
  ∃d4 [(d4 SUB d3) ∧ (d4 PARS d1)]

An overview of the different types of axioms used in MultiNet for the formal specification of relations and functions can be found in appendix E of (Helbig, 2001).

- **Title:** Causality, Relation between Cause and Effect
- **Signature:** $[si' \cup abs'] \times [si' \cup abs']$ (for sorts, see Figure 2)
- **Verbal Description:** The relation (s_1 CAUS s_2) indicates that the real situation s_1 is the cause for the real situation s_2. (The value [FACT = *real*] is symbolized by a prime at the corresponding symbol.) s_2 is the effect which is actually brought about by s_1. The relation CAUS is transitive, asymmetric, and not reflexive.
- **Mnemonics:** (x CAUS y) – [x is the cause of y]
- **Query patterns:** {Why/How is it that} $\langle s_2 \rangle$?
  {Of what/From which $\langle s_1 \rangle$} {[die]/[suffer]/[fall ill]/...} $\langle d \rangle$?
  By what [being caused] $\langle s_2 \rangle$?
  What is the cause for $\langle s_2 \rangle$?
  Which effect {does/did} $\langle s_1 \rangle$ have?
  {Thanks to/Because of} $\langle$WH$\rangle$ $\langle s_1 \rangle$ {[happen]/[occur]/...} $\langle s_2 \rangle$?
- **Commentary:** The causal relationship is closely connected to the temporal successor relation ANTE, since the effect can not take place before the cause:

  - (x CAUS y) $\rightarrow \neg$(y ANTE x)

  There exists also a connection between the relations CSTR and CAUS:

  - (s_1 CSTR d) $\rightarrow \exists\, s_2$ ([(s_2 AGT d) $\vee$ (s_2 INSTR d)] $\wedge$ (s_2 CAUS s_1))

  The following example sentences are typical for the causal relation. The third of them shows clearly that the relation CAUS – in contrast to COND and IMPL – always connects real (not hypothetical) situations, which are characterized by the attribute value [FACT = *real*] .

  [The excitement]$^{\text{CAUS}_{arg2}}$ about [the strange event]$^{\text{CAUS}_{arg1}}$.

  [Peter suffers]$^{\text{CAUS}_{arg2}}$ [from gastritis]$^{\text{CAUS}_{arg1}}$.

  Because [Peter went carelessly across the street,]$^{\text{CAUS}_{arg1}}$
  [he had been run over by a car]$^{\text{CAUS}_{arg2}}$.

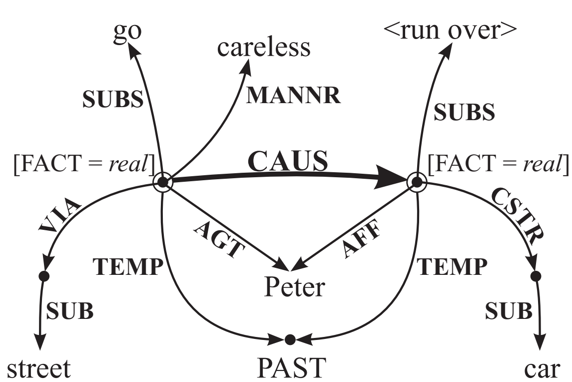

Figure 3: Description of the causal relationship

5 The Stratification of the Semantic Network

One aim of the MultiNet design has been to distance oneself from those network paradigms that press qualitatively entirely different aspects of meaning into one flat structure. For this purpose, the nodes and arcs of MultiNet are embedded in a multidimensional space of so-called layer attributes. The layer specifications for arcs are comprised into an attribute K-TYPE (see point 5, Section 2) and for nodes into another attribute LAY (see Figure 4).

The values of K-TYPE help to distinguish the immanent from the situational knowledge in the semantic network, as discussed in Section 2. The specifications for the attribute LAY are organized along several dimensions, which can itself be described by special attributes having their own values :

- GENER: The **degree of generality** indicates whether a conceptual entity is generic (value: *ge*) or specific (value: *sp*).
  Example: "*(A car)* [GENER=*ge*] *is a useful means of transport.*"
  "*(This car)* [GENER=*sp*] *is a useful means of transport.*"

- 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*).
  Example: "*John* [FACT=*real*] *thought that (he was ill)* [FACT=*hypo*]."
  "*John* [FACT=*real*] *remembered that (he was ill)* [FACT=*real*]."

- 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.
  Example: "*(The passenger)* [REFER=*det*] *observed (an accident).* [REFER=*indet*]."

- QUANT: The intensional **quantification** represents the quantitative aspect of a conceptual entity (whether it is a singleton (value: *one*) or a multitude (values: *two*, *three*, ... *several*, *many*, ... *most*, *all*)). Within the set of values characterizing multitudes, we discern between fuzzy quantifiers like *several*, *many*, ... *most* with value [QUANT = *fquant*] and non-fuzzy quantifiers like *two*, *three*, ... , *all* with value [QUANT = *nfquant*].
  Example: "*(Some house)* [QUANT = *one*] *had been destroyed.*"

- ETYPE: This attribute characterizes the **type of extensionality** of an entity with values:
  nil – no extension,
  0 – individual with an extension that is not a set (e.g. Elizabeth I),
  1 – entity with a set of elements from type [ETYPE=0] as extension
  (e.g.⟨many houses⟩, ⟨the family⟩),
  2 – entity with a set of elements from type [ETYPE=1] as extension
  (e.g. ⟨many families⟩), etc.

- CARD: The **cardinality** as characterization of a multitude at the preextensional level is the counterpart of the attribute QUANT at the intensional level. Thus, the intensional characterization ⟨several members of the crew⟩ sometimes can be made more precise by specifying a concrete cardinality (maybe [CARD=4]) or at least an interval (lets say [CARD=(5, 7)]) for the underlying extension on the basis of additional knowledge or on the basis of a referring expression (e.g. "*six of them ...*").
  Example: "*(A group)* [CARD=1] *of four archaeologistsdiscovered (many tablets)$_i$.*
  Six of (*them* [CARD>6])$_i$ *had been spoiled by the transport.*"

- VARIA: The **variability** finally describes whether an object is conceptually varying (value: *var*) – i.e. it is a so-called parameterized object – or not (value: *con*).
  Example: "*(This policeman)* [VARIA=*con*] *checked (every passport)* [VARIA=*var*]."

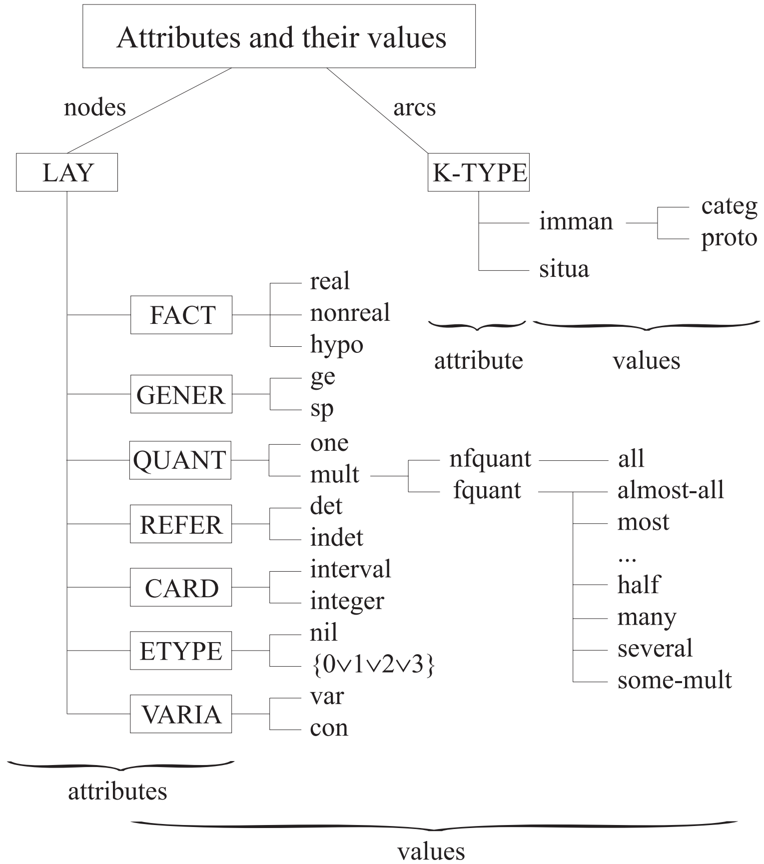

Figure 4: The multidimensional space of layer attributes

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 a (n-1)-dimensional hyperplane. In the same way, if one is fixing one value of a layer attribute (let us assume [GENER=*ge*] or [FACT=*hypo*]), then one gets a special layer or stratum (in this case the layer of all generic concepts or the layer of all hypothetical entities, respectively). Analogously, fixing the value [K-TYPE=*imman*] yields the immanent knowledge about all conceptual entities stored in the knowledge base.

6 The Software Tools connected with the MultiNet paradigm

To support the effective work with MultiNet and the generation of large stocks of information on the basis of this knowledge representation paradigm, MultiNet has been provided with several software tools (a guided tour through these tools can be found on the CD attached to (Helbig, 2001) or at the Internet site
http://pi7.fernuni-hagen.de/research/):

Multinet/WR: A workbench for the knowledge engineer supporting the graphical representation and manipulation of MultiNet networks as well as the accumulation and management of MultiNet knowledge bases. This tool has been developed by Carsten Gnörlich (Gnörlich, 2000).

NatLink: An interpreter which translates natural language sentences into MultiNet semantic networks by means of a word-class controlled syntactic-semantic analysis. NatLink has been developed by Sven Hartrumpf (Helbig and Hartrumpf, 1997).

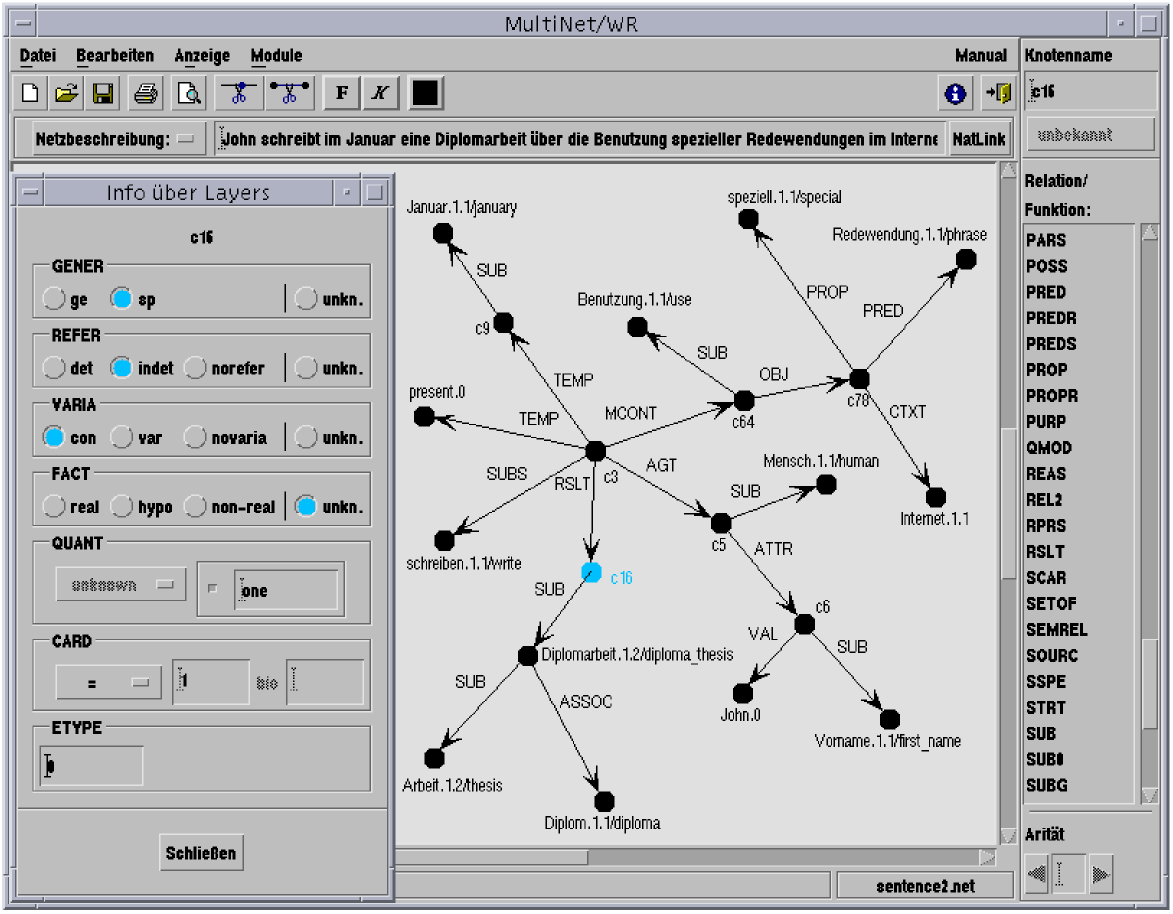

Figure 5: The manipulation and representation of semantic networks with MultiNet/WR

LIA: An interactive workbench for the computer lexicographer which is used to create large semantically oriented computer lexica based on the expressional means of MultiNet. The workbench LIA was initially developed by Marion Schulz (Schulz, 1999) and is now being redesigned and newly developed by Rainer Osswald.

Figure 5 presents a snapshot of the work with the software tool MultiNet/WR showing the semantic representation of the sentences:
(S-G) German: "*John schreibt im Januar eine Diplomarbeit über die Benutzung spezieller Redewendungen im Internet.*"
(S-E) English: "*In January, John writes a diploma thesis about the use of special phrases in the Internet.*"
NatLink can be activated directly from MultiNet/WR (button on the top, right-hand side) taking the sentence presented in the field to the left of this button as input. The result of the analysis is automatically written back on the main working panel of MultiNet/WR. Thus, the basic structure of the network had been automatically created by means of NatLink on the basis of the sentence (S-G). (The English translation (S-E) of the sentence has the same semantic structure as it can be seen from Figure 5. Since NatLink is working at the moment for German only, the labels at the terminal nodes have been added manually by means of MultiNet/WR.)
The networks shown at the working panel of MultiNet/WR can be further edited and manipulated by carrying out several operations:

- Changing the topology of the network by inserting and deleting nodes and arcs

- Changing the layout by moving the nodes and edges, or changing the labels of nodes and arcs, or accessing additional information like viewing and editing the sort or layer information of an activated node (see the pop-up menu at the left side in Figure 5 for the activated node c16 showing its layer specification). Additionally, a complex help system provides the documentation for most elements shown in the working panel, including the explanation of the relations or functions labelling an activated arc (cf. Figure 3 showing the explanation coming up if the help system is activated for an arc labelled by the relation CAUS).

There are also more complicated operations, which can be evoked by means of the buttons at the top bar. They include among others:

- Concatenation of different networks to assimilate them into one knowledge base
- Checking the formal consistency of the network
- Initiating pattern matching processes and inference processes over the semantic network
- Transforming the deep structure of natural language queries into the retrieval language of a data base management system (e.g. into SQL).

7 Conclusion

MultiNet is one of the few knowledge representation systems along the line of semantic networks with a comprehensive, systematic and publicly available description (Helbig, 2001). It has been practically applied in several projects like natural language access to digital libraries in the Internet or as a conceptual interface for information retrieval in multimedia data bases (Knoll et al., 1998). This knowledge representation paradigm is connected with a collection of software tools supporting its use in different application domains. Since MultiNet has been designed as a system for the semantic representation of natural language information, it is especially appropriate for being used as an interlingua in natural language processing systems, which has been proven by the successful application of MultiNet in the above mentioned projects.

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Appendix A: Specification of the Relations and Functions of MultiNet and their Signatures

(This table does not include the lexical relations, the metarelations, and the representational means of the preextensional level. The complete hierarchy of sorts can be found in (Helbig, 2001).)

Relation	Signature	Short Characteristics
AFF	$[si \cup abs] \times [o \cup st]$	C-Role – Affected object
AGT	$[si \cup abs] \times o$	C-Role – Agent
ANLG	$[\ddot{si} \cup \ddot{o}] \times at$	Similarity relation
ANTE	$tp \times tp$	Temporal succession
ANTO	$sort \times sort$	Antonymy relation
ASSOC	$ent \times ent$	Relation of association
ATTCH	$[o \setminus at] \times [o \setminus at]$	Attachment of objects
ATTR	$[o \cup l \cup t] \times at$	Specification of an attribute
AVRT	$[dy \cup ad] \times o$	C-Role: Turning away
BENF	$[si \cup abs] \times [o \setminus abs]$	C-Role – Beneficiary
CAUS	$[si' \cup abs'] \times [si' \cup abs']$	Relation between cause and effect (Causality)
CIRC	$si \times [ab \cup si]$	Relation between situation and circumstance
CONC	$[si \cup abs] \times [si \cup ab]$	Concessive relation
COND	$\tilde{si} \times \tilde{si}$	Conditional relation
CONF	$si \times [ab \cup si]$	External frame, to which a situation conforms
CORR	$sort \times sort$	Relation of qualitative or quantitative correspondence
CSTR	$[si \cup abs] \times o$	C-Role – Causator
CTXT	$[si \cup abs] \times [o \cup si]$	Relation specifying a restricting context
DIRCL	$[si \cup o] \times [l \cup o]$	Relation specifying a local aim or a direction
DISTG	$[\ddot{si} \cup \ddot{o}] \times at$	Distinction between entities
DUR	$[si \cup o] \times [t \cup si \cup abs \cup tn \cup qn]$	Relation specifying a duration
EQU	$sort \times sort$	Equality/equivalence relation
EXP	$[si \cup abs] \times o$	C-Role – Experiencer
FIN	$[t \cup si \cup o] \times [t \cup ta \cup abs \cup si]$	Relation specifying the temporal end
GOAL	$[si \cup o] \times [si \cup o \cup t]$	Generalized goal
IMPL	$[si \cup abs] \times [si \cup abs]$	Implication between situations
INIT	$[dy \cup ad] \times [o \cup si]$	Relation specifying an initial state
INSTR	$[si \cup abs] \times co$	C-Role – Instrument
JUST	$[si \cup abs] \times [si \cup abs]$	Relation specifying a justification
LEXT	$[si \cup o] \times [l \cup m]$	Relation specifying a local extension

LOC	$[o \cup si] \times l$	Relation specifying the location of a situation
MAJ{E}	$qn \times qn$	Greater-then-[or equal]
MANNR	$si \times [ql \cup st \cup as]$	Relation specifying the manner of existence of a situation
MCONT	$[si \cup o] \times [\tilde{o} \cup \tilde{si}]$	C-Role – Relation between a mental process and content
METH	$[si \cup abs] \times [dy \cup ad \cup io]$	C-Role – Method
MEXP	$[st \cup abs] \times d$	C-Role – Mental carrier of a state
MIN{E}	$qn \times qn$	Smaller-then-[or equal]
MODE	$[si \cup abs] \times [o \cup si \cup ql]$	Generalized mode of an occurrence
MODL	$\tilde{si} \times md$	Relation specifying a restricting modality
NAME	$ent \times fe$	Relation specifying the name of an object
OBJ	$si \times [o \cup si]$	C-Role – Neutral object
OPPOS	$[si \cup abs] \times [si \cup o]$	C-Role – Entity being opposed by a situation
ORIG	$o \times [d \cup io]$	Relation specifying an informational source
ORIGL	$[o \cup si] \times [l \cup o]$	Local origin
ORIGM	$co \times co$	Material origin
ORNT	$[si \cup abs] \times o$	C-Role – Orientation towards something
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
PRED	$[\ddot{o} \setminus \ddot{abs}] \times [\overline{o} \setminus \overline{abs}]$	Predicative concept characterizing a plurality
PROP	$o \times p$	Relation between object and property
PROPR	$\ddot{o} \times rq$	Relation between a plurality and a semantic relational quality
PURP	$[si \cup o] \times [si \cup ab]$	Relation specifying a purpose
QMOD	$[s \cup \ddot{d}] \times m$	Quantitative specification
REAS	$[si \cup abs] \times [si \cup abs]$	Generalized reason
RPRS	$o \times o$	Relation specifying a manifestation of an object
RSLT	$[si \cup abs] \times [o \cup si]$	C-Role – Result
SCAR	$[st \cup as] \times o$	C-Role – Carrier of a state
SOURC	$[si \cup o] \times [si \cup o \cup l]$	Generalized source
SSPE	$[st \cup as] \times ent$	C-Role – Entity specifying a state
STRT	$[si \cup o \cup t] \times [t \cup ta \cup abs \cup si]$	Relation specifying a temporal begin

SUB	$[o\backslash\{abs \cup re\}] \times [\overline{o}\backslash\{\overline{abs} \cup \overline{re}\}]$	Relation of conceptual subordination (for objects)
SUBS	$[si \cup abs] \times [\overline{si} \cup \overline{abs}]$	Relation of conceptual subordination (for situations)
SUBST	$[o \times o] \cup [si \times si]$	Relation specifying a representative
SUPPL	$[si \cup abs] \times o$	Supplement relation
TEMP	$[si \cup t \cup o] \times [t \cup si \cup abs \cup ta]$	Temporal embedding of a situation
VAL	$\dot{at} \times [o \cup qn \cup p \cup fe \cup t]$	Relation between attribute and its value
VALR	$\overline{at} \times o$	Relation between attribute and its value restriction
VIA	$[d \cup dy \cup ad] \times [l \cup d]$	Relation specifying a path

Function	**Signature**	**Short Characteristics**
*COMP	$gq \times o \rightarrow tq$	Function describing the comparison of properties
*FLP$_J$	$d \times l$	Family of functions generating locations
*ITMS	$pe^{(n)} \times \ldots \times pe^{(n)} \rightarrow pe^{(n+1)}$	Function enumerating a set
*MODP	$[p \cup m \cup lg] \times p \rightarrow q$	Modification of properties
*MODQ	$ng \times qf \rightarrow qf$	Function modifying quantities
*MODS	$[gr \cup m] \times dy \rightarrow dy$	Function modifying actions
*NON	$md \rightarrow md$	Metafunction for representing negation
*OP$_J$	$qn^w \rightarrow qn$	Arithmetic and other mathematical operations
*ORD	$nu \rightarrow oq$	Function specifying ordinal numbers
*PMOD	$aq \times o \rightarrow o$	Modifcation of objects with properties
*QUANT	$qf \times me \rightarrow m$	Generation of quantities
*SUPL	$gq \times [\overline{o} \cup \dot{o}] \rightarrow tq$	Function describing the superlative
*TUPL	$sort \times \ldots \times sort \rightarrow sort$	Function generating a tuple from its components

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