Computing Granular Word Meanings.
A fuzzy linguistic approach in Computational Semiotics.

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> *The methods and goals of the scientific enterprise may tell us little about human thought in general, just as the symbolic systems constructed appear to differ radically from natural languages in their formal and semantic properties. If so, the picture that has guided the most important work on these topics in the last century may be seriously misconceived.*[1]

Abstract

The notion of *Computing with Words* (CW) hinges crucially on the employment of natural language expressions. These are considered observable and accessible evidence of processes of human cognition, represented by textual structures and actualized in processes of understanding. *Cognitive processes* and *language structures* are characterized by information *granulation, organization* and *causation* which can be modeled both, in their *crisp* as well as *fuzzy* modes of structural representation and functional processing.

In a rather sharp departure from AI and CL approaches, modeling in *Computational Semiotics* (CS) as based on *Fuzzy Linguistics* (FL) neither presupposes rule-based or symbolic formats for linguistic knowledge representations, nor does it subscribe to the notion of world knowledge as some static structures that may be abstracted from and represented independently of the way they are processed. Consequently, knowledge structures and the processes operating on them are modeled procedurally and implemented as algorithms. They determine *Semiotic Cognitive Information Processing* (SCIP) systems as collections of information processing devices whose *semiotic* character consists in a multi-level representational system of working structures emerging from and being modified by such processing. For dynamic cognitive models of natural language understanding, the systems theoretical view suggests to accept natural language discourse as multi-resolutionally structured results of semiotic processes. As such they become empirically accessible and allow for mutual analyses by tracing observable structures back to their constitutive processes and vice versa.

To show the approach's feasibility, examples of soft linguistic categorizing as well as results of dynamic meaning constitution will be derived formally and also computed from discourse data. The new entities' employment will be illustrated by a number of procedures whose properties are discussed as implemented to realize—rather than simulate—language understanding by machine as a *semiotic enactment* of meaning constitution.

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[1] CHOMSKY 1993, p.35

1 Introduction

The notion of *computing with words* (CW) hinges crucially on the employment of natural language expressions. These are considered to provide not only the representational structures of what can semantically be meant but also the operational means of what can cognitively be understood by processing these structures. They allow for decomposition of wholes into their constituents or parts (*granulation*), or conversely, for composition and integration of parts into wholes (*organization*), and for the association of causes with effects (*meaning*). According to ZADEH's early introduction of the notion of *granularity* [69] and his recent elaboration of that concept [71] as *theory of fuzzy information granulation* (TFIG), human cognition may be understood as based upon and structured by processes of *granulation, organization* and *causation*. These are meant to specify different types of mind/brain activities which can be characterized as being computational in nature and hence to be modeled mathematically and/or procedurally. Although this characterization suggests different modes of these mind/brain activities to be distinguished sharply both, as the enactment of processes and as the results which these processes produce—a distinction we will have to draw and obey in what follows—there is the need for yet another discrimination to be made in order to clarify what we will be dealing with here. It is tied to the first one and concerns the way mind/brain activities are made accessible by techniques, models, or disciplines in different ways.

Whereas cognitive approaches tend to model mind/brain processes based upon the evaluation of (in parts linguistic) data generated in (more or less) sophisticated experiments of human thought and understanding, much more immediate results of cognitively most relevant mind/brain activities—not the experimentally reduced segments of them—are being made accessible in the form and structure of natural language discourse. Other than approaches in cognitive linguistics which model the human language faculty under theoretical premises outlined below, some processes of language understanding require and can be modeled along observable but as yet unexploited traces of meaning constitution which speakers/writers and hearers/readers enact in situations of communicative language *use*[2]. This enactment is tied to representational or semiotic functions, based upon regularities of entity *usages*[3] which not only generate observable structures, but also serve in turn to allow these functions being activated to modify these structures simultaneously. Thus, the complexities of natural languages themselves may be taken as a salient paradigm for information granulation both, in its *fuzzy* as well as *crisp* modes of structural representation and functional processing. It appears that the conception of fuzzy and/or crisp *granulation*—once the process-result ambiguity and its cognitive-linguistic ambivalence is solved as addressed by a facet of the symbol-matter problem [30]—lends itself easily to a unifying view of how natural language understanding or *meaning constitution* may be arrived at as a computational process on structural entities adequately identified.

The way structural linguists used to and still categorize (*segment* and *classify*) observable natural language phenomena as *tokens* like *phones, morphs, utterances*, etc. to constitute abstract linguistic entities as *types* like *phonemes, morphemes, phrases*, etc. will be shown to be based on these very processes, however imperfectly. What may procedurally be derived either as *soft linguistic categories* or fuzzy *granules* represented by vectors, distributions, or *fuzzy sets* for (nu-

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[2] In the sense of employment and act of being used under certain conditions and to a particular communicative purpose.

[3] In the sense of customary practice and manner of using which may establish and modify rules and standards.

merical) computation, has so far been (over-)generalized and abstracted to form crisp *categories* represented by signs (*symbols*) for (string) manipulation. Certainly, linear aggregation of these symbols serve to understand and control one type of observable natural language phenomena as part of *string formation* or formal *grammar*. Its core concepts of well-formedness (*syntax*) and truth-function (*semantics*) were made explicit by way of specifying conditions of formal *correctness* and derivational *compositionality*. Their symbolic representations in the form of productions or rewrite *rules*—allowing for recursive application and generative string formation—not only constituted a wealth of symbol aggregation systems (*formal languages*) but were also employed to model comparable properties (in processes) of natural language string formation.

However, whereas formal rules whose application would allow to specify generative properties and truth-functional constraints in formal constructs like *sentence* and *proposition*, other properties of natural language expressions which are communicationally more relevant, like e.g. making *sense* by having specific *meaning* in situational *contexts* which are to be *understood*, tended to be abstracted away. The process of understanding natural language discourse below and above formal sentence reconstruction is, by and large, still in want of principled analysis, formal representation, computational simulation, and procedural realization.

In order to follow this line of structural, functional, simulative, and enactive modeling, traits of traditional approaches to cognition and natural language processing as forwarded by *linguistics proper* (LP), *computational linguistics* (CL), and language processing in *artificial intelligence* (AI) research will be reviewed in order to identify points of departure from which to advance our understanding of how natural languages function the way they do. Some presuppositions will have to be revised to understand how communicative employment of languages is not only based upon (*use*) but also establishes (*usage*) structural constraints[4] which may be made explicit by assumptions motivated by systems theory and/or by empirically testable hypotheses derived thereof. It will be argued that the introspective assessment and judgment of any speakers' own language faculty on linguistic functions and the correctness of singular sentences or phrasal structures as conceived by an *ideal* speaker's/hearer's *internal language* (IL) is not at all sufficient, let alone superior to modern means of empirical investigation of masses of natural language discourse or *external language* (EL) as produced by *real* speakers/writers. Instead, some of the inadequacies of models of natural language processing that *competence oriented* linguistics have inspired so far, will hopefully be revealed to be due to unwarranted abstractions from relevant characteristics (e.g. *contextuality, vagueness, variability, adaptivity, openness* etc., to name only the most salient) of processes of natural language communication. Other than these *idealizations* which purportedly allow immediate access to cognitively relevant entities, we shall argue for an empirically controlled understanding of functional sign constitution which does not readily abstract from the emergent structures which models of a more *semiotic* cognitive information processing (SCIP) may bring about. It is hoped to collect and produce some evidence that the traces of such processing can not only be identified, but that these identification procedures may also be employed to systematically (re)construct *fuzzy information granulation* procedurally.

In *fuzzy linguistic* (FL) models of *computational semiotics* (CS), the situatedness of natural language communication is considered conditional. This requirement is met by corpora of *pragmatically homogeneous texts* (PHT) which assemble language material which is situationally constrained by a number of variables (like e.g. communicative media or domain, register,

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[4] See footnotes 2 and 3 above

topic, author, etc.) whose values (like newspaper, report, economy, etc.) define the PHT profile the incorporated texts will satisfy. There is good reason to assume that such PHT collections realize the *organized* structure of natural language discourse, i.e. integrating parts into wholes (sign formation), as well as the *causative* functions, i.e. associating causes with effects (meaning constitution). The inherent structuredness of a PHT corpus gives rise to the multi-resolutional representations of meaning functions which may be explored in order to model (crisp and fuzzy) SCIP *granules*. Based upon the empirically well founded observation and rigorous mathematical description of universal regularities in natural language discourse, these regularities can be shown to structure and constitute (different levels of) processes and/or their representational results when made to operate on pragmatically homogeneous texts of either performed or intended communicative interaction in actual situations. Only such a *performance oriented* semiotic approach will give a chance to formally reconstruct and model procedurally both, the *significance* of entities and the meanings of *signs* as a function of a first and second order semiotic embedding relation of *situations* (or contexts) and of *language games* (or cotexts) which corresponds to the two-level actualization of cognitive processes in language understanding [54].

Following this *Introduction* (1.) is an exploration of the *Cognitive Background* (2.) with an outline of cognitive modeling (2.1), the relation of language and linguistics (2.2), and the cognitive linguistic approach (2.3) as opposed to the fuzzy linguistic approach (2.4). The conception of *Computational Semiotics* (3.) is developed along the line of an information systems view (3.1), the notion of semiotic enactment (3.2), and the idea of (re)constructive procedures (3.3) considered obligatory on combining *situation* and *language game* semantics in a procedural frame of semiotics. This is tied then to *Fuzzy Linguistics* (4.) with the formal derivation and structured representation of word space (4.1) and semantic hyper space (4.2) as computed from natural language data and actual discourse. Under the heading of *(Re)Constructing Reference* (5.) the semiotic cognitive information processing system devised so far is submitted to an experimental test (5.1) placing it into a language environment of particular, restricted situational conditions (5.2) whose operational processes and results (5.3) are produced to illustrate the SCIP system's performance. After these somewhat preparatory chapters, the realization of *Semiotic Computing with Words* (6.) will outline, illustrate, and discuss the functions (operating on the semantic hyper space data) and the structures (resulting and emerging from that processing) as dispositional dependency structures (6.1), as semiotically generalized constraints (6.2), and their representational properties (6.3) constituting a realizational model of *semiosis*. Finally, the *Conclusion* (7.) tries to summarize some of the innovative points that may also hint towards envisaged areas of possible extension, both theoretical and applicational.

2 The Cognitive Background

For the past decades, the concept of symbolic representation together with the computer metaphor appeared to offer an adequate framework to deal with cognitive processes scientifically. Formally grounded by logical calculi and implemented as algorithms operating on representational structures, cognition is considered a form of information processing in the *cognitive sciences*. Thus, *cognitive theory* has long identified the complex of language understanding as a modular system of subsystems of information processing which could be modeled accordingly. The alliance of logics and linguistics, mediated mainly by (language) philosophy in the past and by (discrete) mathematics since the first half of this century, has long been (and partly still is) dominating in what terms natural languages and their functioning should be explicated and how their processing could be modeled. In replicating (and in parts also supplementing) semiotically motivated strata of systematic sign description and analysis, different levels of modular aggregation of information—external and/or internal to a processing system—have been distinguished in cognitive models of language understanding. They partly correspond to and partly cut across the *syntactics-semantics-pragmatics* distinction in the *semiotic* relatedness of signs, the *utterance-discourse-corpus* levels of *performative* language analysis, and the hierarchy of *morpho-phonological*, *syntax-sentencial* and *lexico-semantic* descriptions in *structural* models of linguistics. It is ironic, however, that the dramatic increase of computational power and symbol manipulation means has changed the fundamentals of many scientific disciplines, creating even new ones, but has left linguistically oriented disciplines, even new ones, adhere to the lore of seemingly well grounded and traditionally dignified concepts—like *phrase* and *sentence*, *predicate* and *proposition*, *grammatical correctness* and *formal truth*, etc.—in describing natural language structures and their functions.

In view of our as yet very limited understanding of the processes constituting natural language understanding which cognitive models and implemented systems of computational natural language processing explicatively offer or demonstrate, it may well be suspected that some of the problems encountered by these model constructions are due to the modeling tools and representational formats they employ in depicting and manipulating entities (elements, structures, processes, and procedures) considered to be relevant or even essential to the understanding of the communicative use of natural languages by humans.

2.1 Modeling Cognition

An earlier attempt by VARELA, THOMPSON and ROSCH [66] to classify model constructions as produced in cognitive science had led to distinguish three types of approaches based on the following characteristics:

- ▷ the *cognitive* approach presupposes the existence of the external world, structured by given objects and properties and the existence of representations of (fragments of) this world internal to the system, so that the cognitive systems' (observable) behavior of action and reaction may be modeled by processes operating on these structures;
- ▷ the *associative* approach is described as a dynamic structuring based on the model concept of self-organization with cognitive systems constantly adapting to changing environmental conditions by modifying their internal representations of them;
- ▷ the *enactive* approach may be characterized as being based upon the notion of *structural coupling*. Instead of assuming an external world and the systems' internal representations of it, some unity of structural relatedness is considered to be fundamental of—and the (only) condition for—any abstracted or acquired duality in notions of the external and internal, object and subject, reality and its experience.

Whereas the first two approaches apparently draw on the traditional rationalistic paradigm of mind-matter-duality—*static* the former, *dynamic* the latter—by assuming the existence of *external* world structures and an *internal* representations of it, the third type does not. Considering the importance that the notions of formatting and representation (both internal and external to an information processing system) have gained in tracing processes on the grounds of their observable or resulting structures, it appears to be justified [55] to add a fourth type:

- ▷ the *semiotic* approaches focus on the notion of *semiosis* and may be characterized by the process of *enactment* too, complemented, however, by the representational impact. It is considered fundamental to the distinction of e.g. *cognitive processes* from their *structural results* which—due to the traces these processes leave behind—may emerge in some form of *knowledge* whose different representational modes comply with the distinction of *internal* or *tacit* knowledge (i.e. *memory*) on the one hand and of *external* or *declarative* knowledge (e.g. *language discourse*) on the other.

According to these types of cognitive modeling, *computational semiotics* (CS) can be characterized as aiming at the dynamics of meaning constitution by *realizing* processes of *simulated*[5] multi-resolutional representation [27] within the frame of an ecological *information processing* paradigm [54]. CS neither depends on rule-based or symbolic formats for (linguistic) knowledge representations, nor does it subscribe to the notion of (world) knowledge as some static structures that may be abstracted from and represented independently of the way they are processed. Instead, knowledge structures and the processes operating on them are modeled as procedures that can be implemented as algorithms.

In particular, the emergence of sign structures as a self-organizing process may be studied on the basis of combinatorial and selective constraints universal to all natural languages. Both, (linguistic) entity and structure formation as well as (semiotic) sign and symbol function may thus be reconstructed as the two aspects of one type of process, constituting and at the same time acquiring *syntagmatic* constraints on linear agglomeration, and *paradigmatic* constraints on selectional choice of elements in natural language discourse. It is extending traditional linguistic analyses that have long—however coarsely—identified and represented their findings as *morpho-phonemic, lexico-semantic, phraseo-syntactic* and *situational* or *pragma-semantic* types of structures. Their regularities may now be exploited at a much finer grain and represented in higher and dynamically adapting resolutions by text analyzing algorithms operating on different levels of structuredness. Ideally, these algorithms accept natural language discourse as input and produce—via intermediate levels of (not necessarily symbolic) representations—interpretable structures of consistent regularities as output. Whereas the intermediate (internal) representations on different levels may be understood as the semiotic system's (hidden) layers of information processing, the system's output structures would represent its state of adaptation to the (external) structures of its environment as signaled and mediated by the natural language discourse processed.

Thus, *semiotic cognitive information processing* (SCIP) can be defined as the cognitive processing of information by humans and/or machines whose semioticity consists in the multi-level representational performance of dynamic (working) structures emerging from and at the same time being modified by such processing which simultaneously constitutes meaning.

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[5] The necessity to distinguish sharply between *simulation* and *realization* [30] in modeling living systems was clarified in desirable detail by PATTEE (see below). It may be related to the even more fundamental issue addressed by CASTI [9] who compared the *internal* structural simplicity (or complexity) of model constructions against their *external* behavioral complexity (or simplicity) by way of their observable and measurable performances. These interdependencies and some of their *semiotic* aspects, however, will have to be dealt with in a separate paper.

2.2 Language and Linguistics

Anything we know or believe about the world can—more or less precisely—be communicated verbally. We do so by language means, employing words, forming phrases and clauses, producing discourse whose meanings are understood to convey, stand for, designate, refer to or deal with topics and subjects, entities and domains, structures and processes in the real world (past, present, or future) or be fictitious altogether, in an entertaining and/or educating sense of understanding. Natural language discourse in the form of spoken or written texts (still) is the most flexible and, as such, highly efficient means to represent knowledge for and convey learning to others.

What appears to be conditional for this kind of text understanding is humans' language faculty, i.e. the *performative* ability to identify, recognize, produce, and structure some fragments of real world material stimuli according to some internal—though externally conditioned—principles. Traditional approaches in *linguistics proper* (LP), *computational linguistics* (CL) and parts of *artificial intelligence* (AI) claim to be interested in and based upon (a subset of) these principles they call language *competence*. Their research endeavors have developed structural and procedural conceptions for (certain aspects of) the process of language understanding. The distinction drawn between *linguistic knowledge* as represented formally in rule based formats, and *world knowledge* whose structuredness is mediated by symbol representational formats has allowed to combine both in a controlled way to model language processing by machine. However, important features characteristic of natural language understanding processes, like e.g. contextuality, vagueness, robustness, adaptivity, distributivity, dynamism, etc. had to be overlooked or intentionally put aside because of the representational formats chosen and the way this choice determined the (entities of) processing. Consequently, computational processing of natural languages as based upon relevant CL and AI research is presently faced by—and partly even undergoing—some fundamental scrutiny. It may broadly be characterized by challenges concerning some of the founding assumptions and basal hypotheses implied in their research *goals* (*Erkenntnisinteresse*), by critical evaluation of their methodological standards in the light of empirical disciplines' quantitative research *methods* (*Untersuchungsmethoden*), and by re-definition of the (proper) linguistic domain of language research *objects* in general (*Forschungsgegenstände*).

2.2.1 The Ruling Tradition: Linguistic Competence

According to Chomsky [11] the cognitive study of natural language phenomena has to be concerned primarily with the *principles* underlying language understanding, i.e. the structure and the organization of the human language faculty (*competence*). It was argued that it may (theoretically) be analyzed and (formally) be characterized well without empirical exploration of observable language data as produced in situations of communicative interaction by real speakers/hearers (*performance*). In a more recent move [13] the speaker's language knowledge or *competence* has been reformulated as *internalized* or I-language whose set of entities (called *lexicon*) aggregatable according to a set of rules (called *computational system*) constitutes the proper domain (called *mental grammar*) of linguistic inquiry. Accordingly, the speakers' *performative* language use named *externalized* or E-language became marginal to that domain and was considered cognitively uninteresting. One of the results which the ongoing discussion [60] may produce is the understanding that the grounding of cognitive linguistic research so far might turn out to be based on a too principled abstraction of language reality [61] as it is experienced—individually and collectively—in communicative discourse interaction.

Taking account of some language regularities and structures which are empirically traceable but may not be identified within the categorial framework of established linguistic concepts[6], and in view also of corresponding tendencies in cognitive linguistics, CL and AI research has come up with some solutions that resulted in increasing complexity and/or narrowing scopes of systems dealing with natural language structures and functions, whereas some empirical studies of *performative* language phenomena were able to provided valuable insights and explanations because of their domains' objects and methods complementary to those of *competence* centered linguistics. Moreover, it appears that empirical approaches based upon quantitative-statistical as well as fuzzy-theoretical model constructions may allow for a more *semiotic* understanding of the functioning of language signs as used by interlocutors in communicative interaction.

2.2.2 The Procedural Challenge: Language Performance

As is well known, computational models of natural language analysis and generation are based upon correct structural descriptions of input strings and their semantic interpretations. This is made possible by rule based representations of (syntactic and lexical) knowledge of a language and of the (referential and situative) world knowledge concerned in formats which grammar formalisms and deductive inferential mechanisms can operate on. Notwithstanding the considerable advances in the development and theoretical testing of increasingly more complex systems, this kind of *cognitive* (or *knowledge-based*) language processing (based on monotone logics, symbolic representations, rule-based operations, sequential processing, etc.) and the essential statics of their representational structures were challenged—although for differing reasons—by connectionist and empirical approaches. These were particularly successful in simulating dynamic properties of processes of cognitive natural language processing (based on the theory of dynamic systems, sub-symbolic or distributed representations, numerically continuous operations, parallel processing, etc.) in *artificial neural network* (ANN) models [28] [33] [8]. There were new insights gained into the wealth of structural patterns and functional relations observed in *very large language corpora* (VLLC) of communicative natural language performance. These insights have partly been specified by results from models of quantitative and statistical analyses (based on probability and possibility theory, stochastic and fuzzy modeling, numerical mathematics and non-monotone logics, strict hypothesizing and rigorous testing, etc.) [1] [23].

The performance of operational ANN implementations successfully applied to problems of string segmentation and classification, to adaptive learning and acquisition, to linguistic entity recognition and identification tasks without prior knowledge of rule-based entity definitions, etc. seemed to allow for everything from controversial skepticism to wildly speculative enthusiasm. Focusing on some of the earlier and more serious contributions to this discussions that the controversy of connectionistic vs. rule-based approaches to models of natural language processing has fueled [63] [17] [64] [59], one will find—overall and in the majority of cases—that these are

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[6] Phenomena like linear short-distance orderings (*Nahordnung*) of performative language entities (e.g. co-occurrences) whose regularities are deprived of rule-based notations but can easily be represented and processed as numerical expressions of correlation values with any precision, are an example in point here. They appear to be the observable results of structuring principles which have been overlooked by competence theoretic investigations only because they do not comply with linear long-distance orderings (*Fernordnung*) that are constitutive of linguistic categories as represented by symbols and processed by familiar grammar formalisms [18] [15] [20].

brought forward from an undisputed epistemological position characteristic of and common to *cognitive linguistics*. Proponents from both sides seem to accept that language *competence*, its principles, components, and their organization is of primary concern to linguistics proper and hence be the basal objective for computational linguistics too. Following the discussion so far, there is a predominant interest in the theoretical aspects of what the different, even *hybrid* model constructions would claim and may justifiably be said to explain [33] [7] [21], not, however, what of new theory constructions or older theoretical constructs' modifications would be necessary to cover and explain hard-core results of empirical and quantitative approaches in language research.

The reasons for this delay are manifold as the availability of masses of performative language data not only require the methodological mastery of a whole spectrum of tools and methods, new to most linguists, but also tend to imply some compensating shift from language *competence* towards language *performance* studies corresponding to a wider domain of research objects for linguistics proper [16] which many computational linguists would refrain from. However, in view of the formal complexity and applicational limitations which rule based cognitive models show on the one hand, and considering the surprisingly efficient practicability of stochastic parsers [14] [4] and statistical machine translation systems [6] [5] on the other, there are good reasons to expect some revision of assumptions and basal hypotheses defining cognitive linguistics. To name only one of the most prominent, is the availability (and globally increasing number) of very large language corpora[7]. These will facilitate to investigate types of natural language properties whose categorial vagueness (uncertain, underdetermined, fuzzily delimited, etc.) or limited to dubious observability (sparse data, uncertain information, etc.) had left them inaccessible and also too often irrelevant to language research. Meanwhile, the processing of VLLC has given abundant evidence that categorial type concepts common in traditional linguistics must be considered highly problematic. When tentatively applied to classify structures which can easily be identified procedurally by quantitative-numerical means, an increasing number of borderline cases, variations, and ambiguities are encountered which cannot be dealt with consistently within the traditional categorial type framework. As these problems appear to result from mappings of structurally highly related data sets to inadequate categories only, these ought to be avoided from the very start. Consequently, classical categorial conceptions in linguistics have begun to be scrutinized and may possibly be substituted by *soft categories* [55] before there is substantial hope to improve chances to understand and to explain *knowledge* as some form of (*world* and/or *language*) structures emerging from information processing models that can truly be called *semiotic*.

2.3 Cognitive Linguistic Mechanisms: Strata

In one of the rare ventures on discussing systematically how cognitive, i.e. knowledge based information processing mechanisms may be provided together with the knowledge bases they are meant to operate on, and how these knowledge structures may be related to observable language data, Bierwisch [3] sketches a hierarchy of information processing mechanisms whose

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[7] The Trier *dpa*-Corpus comprises the complete textual material from the *basic news real service* of 1990–1993 (720.000 documents) which the Deutschen Presseagentur (*dpa*), Hamburg, deserves thanks to have the author provided with for research purposes. After cleaning of editing commands the Trier *dpa*-Corpus consists of approx. 180 million ($18 \cdot 10^7$) running words (*tokens*) for which an automatic tagging and lemmatizing tool is under development. It is this German text corpus which provides the performative data of written language use for the current (and planned) *fuzzy*-linguistic and *computational semiotic* projects at our department.

representational format (sets of rewrite rules operating on structured data) allows algorithms be formulated and implementations be found to guarantee their computability. According to this schema (*Fig.* 1) and starting with the morpho-phonological level, an information processing mechanism M_1 is postulated which accepts *utterances* as input and produces some associated *structures* as output. In doing so, however, the mechanism's performance will be determined not only by the *external* input strings but also by some *internal* knowledge of elements and rules which allow to agglomerate the structures identified. The acquisition and representation of this internal knowledge is hypothesized as resulting from a process M_2 which also includes a multitude of rudimentary, incomplete, and tentative M_1-kind processes. M_2 is assumed to be a complex information processing mechanism whose inputs are *corpora* of utterances together with some environmental information, and whose outputs will be the *grammars* underlying these utterances. Again, this mechanism's results are postulated to be not only and completely determined by the *external* inputs but also by some *internal* structures which are believed to control the human language faculty in a fundamental way as so-called *linguistic universals*. These may (or may not) be assumed to be derivable as results of an information processing mechanism M_3 whose input is as comprehensive (or unspecified) as the term *languages* might allow.

Taking the relation of inclusion for $M_1 \subset M_2$ to hold also for $M_2 \subset M_3$, and considering M_1, M_2, M_3 computationally specifiable procedures of language analyzing processes instead of mere metaphors for some (more or less plausible) mechanisms of the human mind, then it appears reasonable to consider M_3 a (multi-level and structured) collection of all the processes of methodical analysis, representation, comparison, identification, interpretation, etc. for sets of utterances from different languages. This includes the processes in M_1 as a device that explicitly specifies an utterance's structure relative to a given grammar, and the processes in M_2 as a system that generates a grammar from a corpus of utterances relative to the given set of universals M_3. The modeling setup allows for the notions of *Universals* ⇒ *Grammar* ⇒ *Structure* to be understood as variables of theoretical constructs hinged on empirical regularities observed in *Languages, Corpora, Utterances* respectively. Whereas the latter are considered *external* language realizations, the former are hypothesized to be constraints *internal* to any natural language or cognitive information processing system which may be represented externally only under the competence linguistic approach to cognitive modeling. Thus (following the double arrows in *Fig.* 1), these will form a hierarchy of *linguistic*[8] abstractions—not of *language* entities which may formally be specified by (other types of) abstractions and represented by symbols.

The model theoretical and operational problems inherent in this setup concern the (non universal and highly restrictive) representational format which is assumed to enable the denotation of *universals, grammar* and *structure*, and the essentially top-down[9], non-recursive propagation of *externally* presented but *internally* processed results of these mechanisms. Thus, completeness of M_3 in identifying universals and representing them externally is crucial for the efficient performance of M_2 which is to employ these universals as internal, procedural constraints in order to identify syntactic regularities successfully. Represented externally in a rule based format, these

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[8] The term is polysemous in English as it might likewise be understood as the adjectival form of *language* and of *linguistics*. To allow for a distinction of these two meanings which some other languages have in fact lexicalized (by different words), we will confine *linguistic* to denote properties of (the theories, models, methods, goals, concepts, etc. of) *linguistics* as the scientific discipline investigating natural languages, and *language-like* to refer to those of (observable or experiential) language phenomena.

[9] Although in *Fig.* 1 these strata are given in inverse (bottom-up) order.

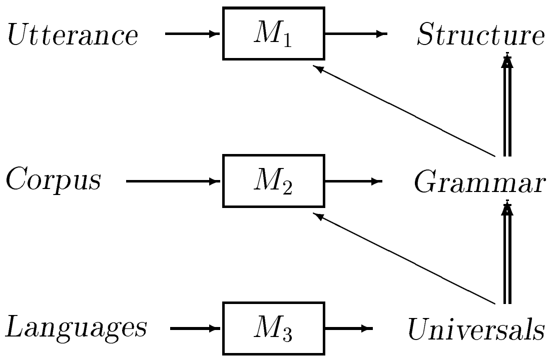

Figure 1: Schema of the model hierarchy of *cognitive linguistic* strata determined by mechanisms M_1 to M_3 that constitute *Structure, Grammar* and *Universals* from *Utterance, Corpus* and *Languages* respectively, identifying and defining the principled constraints *Universals*$\rightarrow M_2$ and *Grammar*$\rightarrow M_1$ on these strata (according to BIERWISCH 1981).

rules will constitute possible formal grammars. Grammars, in turn, are meant to provide the internal procedural constraints in M_1 in order to let these mechanisms' identification processes represent their findings successfully as discretely categorized external structures.

Distinguishing between these two kinds of structuredness either *external* or *internal* to the mechanisms M—as introduced by BIERWISCH—not only anticipates important components of CHOMSKY's notion of *mental grammar* and his distinction of E- and I-languages. But the distinction is also indicative of the *endo-exo* dichotomy whose introduction on this level of modeling may be questioned as an *ad hoc* abstraction from, not a result of the procedural unity which a systems theoretical view on information processing allows to keep up in semiotic modeling. The mechanisms M_1 to M_3—if provided—easily translate to sets of procedures which determine and *simulate* but hardly *realize* a living systems' ability to process environmental input (external structures) according to procedural constraints known to the system (internal structures) in order to produce not only some results as material part of the (external) environment but simultaneously also some feedback effecting the system's (internal) structure.

In fact, it appears not at all conclusively compelling to assume that such constraints and their procedural enactment need to be represented in a format of rule type expressions. Certainly, according to an ecologically motivated systems theoretical perspective, enacting these processes under boundary conditions as determined by the external surroundings or the systems' internal structuredness, or both, will have to be exposed to certain input structures to produce specified output structures. But identifying their status of being at the same time internal and external to the processing system is tantamount to the methodological dilemma which can solely be solved on the grounds of revising the representational mode and the formatting constraints which the model construction has to be decided on to allow. Apparently, CHOMSKYan linguistics has restricted both these modes to consist of abstract principles of language competence whose assumed determinacy subsequently allowed for symbol representations in the form of rewrite-rules or productions. These in turn gave rise to the above model hierarchy of discrete strata which only lately—under pressure of urgent practical solutions to circumvent difficulties resulting from the above dilemma's methodical obstructions—became meshed by unification mechanisms in corresponding grammar formalisms.

In trying to relate these strata to observable performative language data structures in order to mediate observable language regularities with theoretical constructs supposedly representing principles underlying these constructs, the methodological shortcomings of the cognitive linguistic approach are revealed. It suffers from competence theoretically inspired idealizations and theoretical abstractions (like *universals, grammars, sentences*) whose symbolic notations and formal expressions may only be scrutinized for their syntactic correctness but lack empirically developed and experimentally testable procedures. Such procedures would have to relate the formal expressions—supposedly representing competent speakers' language understanding faculties—to performative language regularities observable in discourse, and would also—instead of presupposing some (symbolic) abstractions of these regularities—make them detectable as one of their procedurally *realized* modeling results.

2.4 Fuzzy Linguistic Procedures: Tiling

It is *structural linguistics* (SL) which has given substantial hints on how abstract linguistic entities (*types*) may be identified from observable language items (*tokens*) by segmentation and classification of resemblances of entities' distributional patterns as employed and discovered in communicative discourse. The structuralistic view of natural languages has produced the seminal distinctions of *langue–parole* (DE SAUSSURE) on the hand, and of *competence/performance* or *I-language/E-language* (CHOMSKY)on the other, providing modern linguistics with two different realms of language description and linguistic analysis. It is grounded in the possibility to abstract (formal) *linguistic entities* from (empirical) *language data*, and in the discovery of principles of combinatorial constraints responsible for string formation in natural languages. Tied to comparative operations, these allow to *segment* token strings of language discourse and to *categorize* segments as classes of types of linguistic entities.[10]

An overview of linguistic approaches to word semantics, from traditional (crisp) models to semiotic structures of (fuzzy) word meaning analysis, representation, and processing, lends itself quite naturally to illustrate the point to be made here. By taking up the lore of terminological distinctions, some of the *organizational* and *granular* aspects underlying traditional linguistic categorizing may be revealed: closed classes (*functional words*) as opposed to open classes (*contents words*), the latter consisting of simplicia (*lexical*) and compounds of (morphologically) either *derivational* or *flexional* origin, and the former breaking down in logical constants (like *and, or, not, all, if...then*, etc.) and linguistic functions (like *at, by, for, in, on*, etc.) with characteristic functional equivalences on various levels across different languages. In particular, the open class of *contents words* display the mechanisms of morphologically relevant sign aggregation and entity formation regularities most clearly which led structural linguists to identify the fundamental constraints (*universals*) that control the linear combinability and multi-level formation of language structures in distinguishing restrictions on their linear aggregation (*syntagmatics*) from restrictions on their selective replacement (*paradigmatics*). This distinction allows within any

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[10] From an *enactive* approach to modeling cognition, the very possibility of distinguishing these segmented *token observations* from classified *type abstractions* corresponding to them, can be considered evidencial for natural language discourse as an instanciation of structure which serves both, as a controlling constraint and an emergent result when employed. It is this two-fold ontology that renders communicative discourse a *structural coupling* the analytical use of which can be made by any *semiotic cognitive information processing* (SCIP) system properly attuned to that natural language environment.

sufficiently large set of strings of natural language discourse to ascertain syntagmatic regularities of linear element aggregations on level n whose characteristic distributional patterns can be classified to form paradigms which generally acquire aggregational element status again on level $n+1$, and so forth. As such constraints have been detected in both directions (*bottom-up* and *top-down*) and represented for different levels $(n-1, n, n+1)$ of linguistic entity formation, some of these entities may indeed be identified with the well-established, traditional strata of linguistic analysis and description of language phenomena.

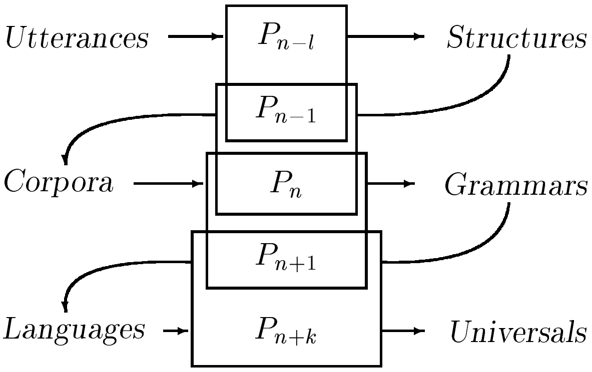

Figure 2: Schema of model tiling or (overlapping) *computational semiotic* coverage of procedures P_{n-l} to P_{n+k} for the analysis and representation of (detected) language regularities in *Utterances, Corpora* and *Languages* and of (constituted) fuzzy linguistic or soft categories mediating between *Structures*→*Corpora* and *Grammars*→*Languages* (according to RIEGER 1996).

The combinatorial redundancies resulting in observable (language) regularities may not only—if sufficiently overt—be expressed by (linguistic) symbols and their linear aggregations be represented by sets of (deterministic) rules formatted accordingly. But also less overt observable redundancies may quite as well be taken as an efficient, i.e. recursively applicable principle of complexity reduction by multi-resolutional bottom-up *representational organization* or top-down *information granulation*. Detecting and identifying regularities, then, allows for at least two kinds of multi-resolutional modeling:

- ▷ the categorial type of constraints symbolized by fully deterministic *if-then rules* will result in a rather coarse three-level hierarchy (*Fig.* 1) of symbolic representations of mechanisms or *crisp information granules*;
- ▷ identifying regularities as probabilistic or possibilistic constraints will produce a continuous covering or multi-level tiling (*Fig.* 2) of dynamic distributional representations realized as procedures or *fuzzy information granules*.

Thus, it can be distinguished sharply between cognitive crisp categorial, rule based, symbolically represented *linguistic mechanisms*[11] and soft categorial, regularity based, distributedly represented *semiotic procedures* whose computations transform structured input data according to

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[11] Although these *mechanisms* may also be translated to procedures and—when implemented as algorithms—to operational processes, they do not hereby acquire *semiotic* status. Other than transforming hidden structures into their representations by exploiting n-level inherent constraints of training data to constitute $n+1$-level significations of them (i.e. *realization*), cognitive linguistic systems claiming to be procedural are confined to transforming input structures according to symbolically predefined representational formats external to the structuredness they are meant to model (i.e. *simulations*).

its immanent regularities to yield new, structural representations emerging from that computation (as hypothesized by *fuzzy linguistics* and realized in procedural models of *computational semiotics*).

The elements of these new model structures are value distributions or vectors of input entities that depict properties of their structural relatedness, constituting multi-dimensional (metric) space structures (*semiotic spaces*) instead of formally correct string expressions from externally interpreted calculi (*formal languages*). As a weaker or *soft* analogue to the principles of formal languages, these space structure elements may, however, be interpreted as systems of subsystems of *fuzzy sets* allowing set theoretical operations be exercised on these representations that do not require categorial type (*crisp*) definitions of concept formations or predefined propositional structuredness.

Other than cognitive linguistic and competence theoretical *mechanisms*, the proposed [55] cognitive semiotic and language performative *procedures* re-define the modularity of language understanding as an overlapping covering of computational processes. The classical and coarse three-stage description and modeling of linguistic regularities (*Fig.* 1) will be replaced—or rather complemented [38]—by a multi-stage covering or tiling of *semiotic* procedures P_{n-l} to P_{n+k} (*Fig.* 2). This allows for the definition of more adequate soft categories or intermediate representations to fit regularities of entities on any level. Their essentially cognitive character will not be borrowed from predefined strata (and their purportedly related abstract categories) but can be derived as a result of the algorithms' analyzing and representational performance, i.e. the ability to transform linearly structured entities (strings) of one level to multi-dimensional structures of entities (vectors) on another. Their (numerical) specificity and (procedural) definiteness, as well as their sub-symbolic, distributional format appear to provide for higher phenomenological compatibility and more cognitive adequacy in modeling processes and results of entity formation than traditional levels of categorial representation whose symbolic mediation and syntactic correctness could only formally be scrutinized but not empirically or experimentally be tested [38].

How this is achieved by analyzing the linear or *syntagmatic* and the selective or *paradigmatic* constraints which natural language structure imposes on the formation of (strings of) language signs on whatever level of entity formation, has been derived elsewhere [50] in some detail, and will be illustrated more concisely below.

3 Computational Semiotics

Inspired by *information systems theory* [54], human beings may be taken as living *systems* whose knowledge based processing of represented *information* makes them *cognitive*, and whose sign and symbol generation, manipulation, and understanding capabilities render them *semiotic*. Due to our own daily experience of these systems' performance and ability in representing results of cognitive processes, in organizing these representations, and in modifying them according to changing conditions and states of system-environment adaptedness it is argued [55] that the *semiotic approach* to modeling human cognition—constituting *computational semiotics*—will have to be grounded in such complex semiotic cognitive information processing. Consequently, it has to be based upon the representational structures resulting from and initiating such processing, i.e. natural language discourse. In the aggregated form of *pragmatically homogeneous text* (PHT) corpora [35], communicatively performative natural language discourse provides a cognitively revealing and empirically accessible system whose multi faceted structuredness may serve as guideline for the cognitively motivated, empirically based, and computationally realized research in the semiotics of language.

3.1 Information Systems View

The ecological view of information processing arose out of the investigation of animal-environment interaction which formed the basis of GIBSON's theory of perception [19] and the school of ecological realism [66] that has been based on it. Following an ecological paradigm of systems theory (providing a concept of pragmatic information [67] relativ to system-environment situations) and accepting the cognitive point-of-view (implying that information processing is knowledge based), human beings appear to be not just natural information processing systems with higher cognitive abilities. Instead, they have to be considered very particular cognitive systems whose outstanding plasticity and capability to adapt to changing environmental conditions is essentially tied to their use and understanding of natural languages in communicative discourse. It seems that the language faculty expands their learning potential well beyond experimental experience into realms of virtual reality (*Gedankenexperimente*). The basic idea of model construction in terms of such an ecological theory of information systems [54] is that the processing structure of an information system is a correlate of those structures which such a system is able to process in order to survive.

3.1.1 Ecological Information Processing

Life may be understood as the ability to survive by reproduction and adaptation to changing requirements in the real world. In terms of the ecological theory of information systems, faculties like perception, identification, and interpretation of structures (external or internal to a system) can hence be conceived as a form of *information processing* which (natural or artificial) systems—due to their own structuredness—are able to perform. Thus, living systems receive or derive information from relevant portions of their surrounding environments, they learn from experience, and change their behavior accordingly. In contrast to other living systems which transmit experiential results of environmental adaptation only biogenetically[12] to their descendants, human information processing systems have additional means to convey their knowledge to others. In addition to the *vertical* transmission of system specific (*intraneous*) experience through (biogenetically successive) generations, mankind has complementarily developed *horizontal* means of mediating specific and foreign (*extraneous*) experience and knowledge to (biogenetically unrelated) fellow systems within their own or any later generation. This is made possible by a *semiotic* move with the affordance of *memory* that allows not only to distinguish *processes* from *results* of experience but also to convert the latter into *knowledge* facilitating it to be re-used, modified and even improved by *learning*. Vehicle and medium of this move are *representations*, i.e. material systems (abstract *languages*) formed of recurrent structures (both, elementary and composite) constituting sign functions of arbitrary complexity (*textures*) which may be realized in communicative processes, called *actualization*.

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[12] According to standard theory there is no direct genetic coding of experiential results but rather indirect transmission of them by selectional advantages which organisms with certain genetic mutations gain over others without them to survive under changing environmental conditions.

3.1.2 Modes of Representation

In terms of the theory of information systems, representations (*textures*)—whether internal or external to the systems—function like virtual environments[13]. Considering the system-environment relation, *virtuality* may generally be characterized by the fact that it dispenses with the identity of space-time coordinates for system-environment pairs which normally prevails for this relation when qualified to be indexed *real*. It appears, that this dispensation of this identity—for short: space-time-dispensation—is not only conditional for the possible distinction of *systems* (mutually and relatively independent) from their *environments*, but also establishes a notion of *representation* which may be specified as exactly that part of a time-scaled *process* that can be separated and identified as its outcome or *result* in being (or becoming) part of another time-scale[14]. Accordingly, *immediate* or space-time-identical system-environments without representational form may well be distinguished from *mediate* or space-time-dispensed system-environments whose particular representational import (*texts*) corresponds to their particular bivalent timely status both, as longer-term material (composed of language *signs* having virtual *meaning*), and as shorter-term structure (in need of being *(re)cognized* in order to be *understood*)[15]. This double identity calls for a particular modus of actualization (*understanding*) that may be characterized as follows:
For systems appropriately adapted and tuned to such virtual environments, *actualization* consists essentially in a twofold embedding to realize

- ▷ the spacio-temporal identity of pairs of *immediate* system-environment coordinates which will let the system experience the material properties of texts as *signs* (i.e. by functions of *physical access* and *mutually homomorphic* appearance of structures). These properties apply to the percepts of language structures presented to a system in a particular *discourse situation*, and
- ▷ the representational identity of pairs of *mediate* system-environment parameters which will let the system experience the semantic properties of texts as *meanings* (i.e. by functions of *identification, granulation, organization, emergence, activation, modification* of structures). These virtual properties apply to the comprehension of language structures recognized by a system to form the *described situation*.

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[13] SIMON's (1982) remark "There is a certain arbitrariness in drawing the boundary between inner and outer environments of artificial systems. ...Long-term memory operates like a second environment, parallel to the environment sensed through eyes and ears" (pp. 104) is not a case in point here. Primarily concerned with where to place the boundary, he does not seem to see its placing in need to be justified or derived as a consequence of some possibly representational processes we call *semiotic*. As will become clear in what follows, Simon's distinction of *inner* (memory structure) and *outer* (world structure) environments is not concerned with the special quality of language signs whose twofold environmental embedding (textual structure) cuts across that distinction, resolving both in becoming representational for each other.

[14] It is tempting to extend the conception of different *linear* time scales to that of differently scaled time *cycles*, particularly in view of the resolutional power of representations and their semiotic processing in computational models – which can only be alluded to here.

[15] In view of natural languages discourse there is yet another distinction to be mentioned, although not enlarged upon here, which is due to systems theoretical differences of verbal or auditorially, as opposed to written or optically mediated language environments for interlocuting systems. Whereas the former may be characterized for participating systems as either space-time identical (e.g. face-to-face communication) or space dispensed (e.g. videophone conversation) environments, the latter or scripture based interaction will generally dispense with the space-time coordinates' identity of system-environment pairs concerned (e.g. papyri), allowing however space identity (e.g. mural inscriptions

Hence, according to the theory of information systems, functions like *interpreting* signs and *understanding* meanings translate to processes which extend the fragments of reality accessible to a living (natural and possibly artificial) information processing system beyond reality's material manifestations[16]. This extension applies to both, the *immediate* and *mediate* relations a system may establish according to its own evolved adaptedness or dispositions (i.e. innate and acquired *structuredness*, processing *capabilities*, represented *knowledge*).

3.2 Semiotic Enactment

Semiotic systems' ability to actualize environmental *representations* does not merely add to the amount of experiential results available, but constitutes also a significant change of experiential modus. This change is characterized by the fact that *processes* of experience may be realized as being different and hence be separable from the *results* of that experience. Whereas in *immediate* system-environment situations, processes without traceable representations appear to be indistinguishable from their results, *mediate* system-environments are constituted by this very distinction[17]. Being able to distinguish experiential modi like these is tantamount to the emergence of *virtual* experiences which have not to be *made* but can instead just be *tried* and tested, very much like hypotheses in experimental settings (*thought experiments*). The *results* of such tentative experiencing may become part of a system's adaptive knowledge as acquired in *immediate* system-environments, but may also—other than in *immediate*, however characteristic of *mediate* system-environments—be neglected or selected, accepted or dismissed, varied and repeatedly actualized and re-used without any risk for the system's own survival, stability or adaptedness.

This in a way experimental quality of textual representations which increases the potentials of adaptive information processing beyond the system's life span, is constrained simultaneously by *dynamic* structures corresponding to *knowledge*. The built-up, employment, and modification of these structural constraints[18] is controlled by procedures whose processes determine *cognition* and whose results constitute *adaptation*. Systems properly attuned to textual system-environments have acquired these structural constraints in language learning and can perform certain operations efficiently on them in language understanding. These are prerequisites to (re)cognize *mediate* (textual) environments, to respond to their needs for—and to enact the systems' own abilities of—*actualizing* a process the mutual (and threefold) relatedness of which PEIRCE identified to constitute what he called *semiosis*[19]. Systems capable of and tuned to such knowledge-based processes of actualization will in the sequel be referred to as *semiotic cognitive information processing* (SCIP) systems [52] [53].

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[16] It might be argued that—if anywhere—the problem of modeling *consciousness* (whether posed as a *soft* or *hard problem* [10] or neither [29]) could be addressed on these grounds, i.e. as an integral quality of system-environment situations whose dynamics as mediated by self-organizing material structures acquire interpretable meanings for SCIP systems properly attuned (with the understanding that the notion of *attunement* is semiotic whereas *adaptation* is functional).

[17] Splitting up experience in experiential processes and experiential results—the latter being representational and in need for procedural actualization by the former—appears to be at the base of all *endo-exo* distinction of structures being *internal*, from those being *external* to an information processing *system* which thereby becomes separated from its *environment*.

[18] What SIMON (1982) calls *memory* in accordance with his questioning of the inner-outer-distinction of cognitive systems and their environments.

[19] See footnote 23 below.

In modeling SCIP systems' performances, the concept of *representation* has to be considered fundamental to the computational semiotic approach to cognition, allowing to realize—instead of simulating—the experiential distinction of semiotic *processes* of cognition from their *results* which emerge—due to the traces these processes leave behind—in some structures (*knowledge*). Different representational modes of this structure not only comply with the distinction of *internal* or *tacit* knowledge (as e.g. in modeling *memory*) on the one hand and of *external* or *declarative* knowledge (as e.g. in representations of *discourse*) on the other[20], these modes also relate to different types of (*distributional* vs. *symbolic*) formats, (*connectionist* vs. *rule-based*) modeling, and (*stochastic* vs. *deterministic*) processing.

It is this range of correspondences that *Fuzzy Linguistics* (FL) is based upon and tries to exploit to come up with a unifying framework for most of the different approaches followed so far. *Soft categorizing* appears to be a prerequisite for fuzzy linguistic models examples of which will illustrate the notion of dynamic structures emerging from corpora of natural language discourse.

3.3 (Re)Constructive Procedures

In systems theory, it is common to look at systems in two ways: *externally* by its behavioral characteristics, i.e. the way how a system performs in processing (controlled or known) input and producing (observable or measurable) output, and *internally* by the structural characteristics, i.e. the number and kind of variables in the system and how these variables are organized and connected to each other.

From the model constructor's position it was pointed out [31] that the matter-symbol, the material-sign, or the structure-function distinctions are difficult to determine in (primitive) organisms' behavior, quite contrary to the sharp distinction drawn in models of dynamic physical behavior[21]. This, mainly, is due to the fact that only from the modeler's external view the organisms' processing of environmental information appears to be based upon principled structures (*representations*) of processing results whereas an organism's own (internal) processing may in fact do very well without such representational structures and apparently survives on merely performing some sorting procedures or classification functions allowing to identify the relevant (and to ignore the irrelevant) components in its surroundings, possibly—but not necessarily—based on prior experience in similar situations. Therefore, relating *structure* to *function* may well be considered but another aspect of how the notion of representation (internal or external to a system) can be *realized* instead of *simulated* in a system-environment model of cognitive information processing.

> First, simulations and realizations belong to different categories of modeling. Simulations are metaphorical models that symbolically "stand for" something else. Real-

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[20] Whereas *tacit knowledge* cannot be represented other than by the *immediate* system-environments' corresponding states, *explicit knowledge* is bound to acquire some formal properties in order to become externally presented and thereby part of *mediate* system-environments. Natural languages obviously provide these formal properties—as partly identified by research in linguistic competence (principled knowledge and acquisition of language)—whose enactment—as investigated in studies on natural language performance (production and understanding of texts)—draws cognitively on both bases of (explicit and tacit) knowledge.

[21] "As external modelers we need to know the detailed chemical structure of DNA to understand, and perhaps to design, the chemical correlates of its function, but to perform its semantic function in the cell only the cell's classification of the base sequence is relevant to the synthesis of proteins." (Pattee 1995, p.12)

> izations are literal, material models that implement functions. Therefore, accuracy in a simulation need have no relation to quality of function in a realization. Secondly, the criteria for good simulations and realizations of a system depend on our theory of the system. The criteria for good theories depend on more than mimicry, e.g. Turing Tests. Lastly, our theory of living systems must include evolvability. Evolution requires the distinction between symbolic genotypes [*types* of language entities], material phenotypes [*tokens* of language entities], and selective environments [*situations* of communicative language use]. Each of these categories has characteristic properties that must be represented in artificial life (AL) models.[22]

For cognitive models of natural language processing the systems theoretical view suggests to accept natural language discourse as analyzable and empirically accessible evidence for tracing such processes. Thus, natural language discourse might reveal essential parts of the particularly structured, multi-layered information representation and processing *potential* to a system analyzer and model constructor in rather the same way as this potential is accessible to an information processing system trying to understand these texts. There is an important difference, however, in dealing with the natural language material which is part of an information processing system and its analyzer on the one hand, and also part of an information system engaged in processing its discourse environment on the other. Distinguishing between the object-modeler relation and the system-environment relation is to be active in and part of different information processing *situations* of which only the latter—and not the former—can be said to be directly accessible to the modeler via attunement.

It is this lack of being properly *attuned* to the *semiotic* principles underlying natural language understanding systems which prompts cognitive linguists to fall back on situations they are attuned to, namely natural language understanding whose formal abstractions they believe to be provided by principled *IL* representations of language *competence*. But whereas in communicative language understanding one can—and even has to—take the *semiotics* of signs and the constitution of meanings for granted and beyond questioning (i.e. signs and meanings are meant to be understood, no matter whether fully or only partially, whether correctly or even wrongly), the purpose of modeling that very process (i.e. how structures become signs, meaning is constituted, and language understood) must not. Trying to understand (conditions of possible) understanding of signs and meanings cannot rely on the *simulative* processing of (symbol) structures whose representational status is declared by drawing on a pre-established semantics (known by the modeler, made accessible to the model, but not at all compulsory for the system modeled). Instead, modeling processes of meaning constitution or *understanding* will have to *realize* that very function in an implemented and operational information processing system which is able to render some structure—in a self-organizing way—representational of something else, and also allows to identify what that structure is to stand for. This is—very briefly—what establishes a *symbol* or sign-meaning relation whose *semantics* is a way of representing this relation in an overt and intelligible sense to other (natural and/or artificial) *semiotic cognitive information processing* (SCIP) systems. The notions of *discourse situation* and of *language game* will serve to mediate the dynamics of *semiosis* and the procedural approach to model SCIP systems as based upon natural language discourse.

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[22] Pattee 1989, pp.63; [my parentheses, BR]

3.3.1 Discourse Situations

Situations (comprising *system*, *environment*, and *processing*) are considered *cognitive* inasmuch as the system's internal (formal and procedural) knowledge has to be applied to identify and recognize structures external to the system (*meaning interpretation*). These situations become *semiotic* whenever the internal knowledge applied to identify and interpret environmental structures is derived from former processes of external structure identification and interpretation, and applied as the result of self-organizing feedback through different levels of (inter-)mediate representation and organization. This process (of *meaning* constitution or structure *understanding*) is the multiple enactment of the threefold relation which is called—following Peirce—*semiosis*[23]. The triadic relation allows for different ontological abstractions of *language*

- ▷ as a component (*sign*) in a system's external environment, i.e. material *discourse* as a physical space-time location;
- ▷ as a constituent of virtuality which systems properly attuned experience as their environment (*object*), i.e. structured *text* as an interpretable potential of meanings, and
- ▷ as a process of actualization (*interpretant*) in a particular system-environment situation, i.e. *understanding* as the constitution of meaning.

According to Barwise and Perry [2] any language expression is tied to reality in two ways: by the *discourse situation* allowing an expression's meaning being *interpreted* and by the *described situation* allowing its interpretation being *evaluated* truth-functionally. Within this relational model of *Situation Semantics meaning* may be considered the derivative of information processing which (natural or artificial) systems—due to their own structuredness—perform by recognizing similarities or invariants between situations that structure their surrounding realities (or fragments thereof).

By ascertaining these invariants and by mapping them as *uniformities* across *situations*, cognitive systems properly *attuned* to them are able to identify and understand those bits of information which appear to be essential to form these systems' particular views of reality: a flow of *types of situations* related by *uniformities* like e.g. individuals, relations, and time-space-locations. These uniformities constrain a system's external world to become its *view of reality* as a specific fragment of persistent (and remembered) *courses of events* whose expectability (by their repetitiveness) renders them interpretable or even *objective*.

In semiotic sign systems like natural languages, such uniformities appear to be signaled also by sign-*types* whose employment as sign-*tokens* in texts exhibit a special *granular* form of *structurally conditioned* constraints. Taking the entity *word* as an example from the granular tiling of semiotic sign structures, then these words and the way they are used by the speakers/hearers in discourse do not only allow to convey/understand meanings differently in different discourse situations (*efficiency*), but at the same time the discourses' total vocabulary and word usages also provide an empirically accessible basis for the analysis of *structural* (as opposed to *referential*) aspects of *event-types* and how these are related by virtue of word uniformities across phrases, sentences, and texts uttered. Thus, as a means for the *intensional* (as opposed to the *extensional*) description of (abstract, real, and actual) *situations*, the regularities of word-usages may serve as an access to and a representational format for those elastic constraints which underlie and condition any word-

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[23] "By *semiosis* I mean [. . .] an action, or influence, which is, or involves, a coöperation of *three* subjects, such as sign, its object, and its interpretant, this tri-relative influence not being in any way resolvable into actions between pairs." (Peirce 1906, p.282)

type's *meaning*, the *interpretations* it allows within possible contexts of use, and the *information* its actual word-token employment on a particular occasion may convey.

Under these preliminary abstractions, the distinction between (the format of) the representation and (the properties of) the represented is not so much a prerequisite but rather more of an outcome of *semiosis*, i.e. the semiotic process of sign *constitution* and *understanding*. Consequently, it should not be considered a presupposition or *input to*, but a result or *output of* the processes which are to be modeled procedurally and implemented as a computational system justified to be named *semiotic*.

3.3.2 Language Games

According to WITTGENSTEIN [68] the notion of *language game*[24] characterizes a very fundamental type of discourse situations "complete in themselves, as *complete systems* of human communication" and solely concerned with the way of how signs are used. Operationalizing this notion and analyzing a great number of texts for *usage regularities* of terms can reveal essential parts of the concepts and hence the meanings conveyed by them. This approach as conveyed in [37] has also produced convincing evidence that an analytical procedure appropriately chosen can be identified with a mechanism which simultaneously solves also fundamental representational tasks if based upon algorithms that simulate the combinatorial constraints operational in *syntagmatics* and *paradigmatics* known to be universal to all natural languages.

The philosophical concept of *language game* can be combined with the formal notion of *situation* allowing not only for the identification of a cognitive system's (*internal*) structure with the (*external*) structure of that system's environment. Being tied to the observables of actual language performance enacted by communicative language usage also opens up an empirical approach to procedural semantics and *computational semiotics*. Whatever can formally be analyzed as *uniformities* in BARWISEian *discourse situations* may eventually be specified by word-type regularities as determined by co-occurring word tokens in samples of pragmatically homogeneous texts as representations of *language games*. Going back to the fundamentals of structuralistic descriptions of regularities of *syntagmatic* linearity and *paradigmatic* selectivity of language items, the quantitative, two-level analyses of discourse entities' correlational behavior will allow for a multi-resolutional word meaning and world knowledge representation whose dynamism is a direct function of elastic constraints established and/or modified in language communication.

As has been outlined in some detail elsewhere [40] [43] [47] [57], the meaning function's range may be computed and simulated as a result of exactly those (semiotic) procedures by way of which (representational) structures emerge and their (interpreting) actualization is produced from observing and analyzing the domain's regular constraints as imposed on the linear ordering (*syntagmatics*) and the selective combination (*paradigmatics*) of natural language items in communicative language performance. For natural language semantics this is tantamount to (re)presenting a term's meaning potential by a fuzzy *distributional pattern* of the modeled

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[24] "These are ways of using signs simpler than those in which we use the signs in our highly complicated everyday language. *Language games* are the forms of language with which a child begins to make use of words [...] If we want to study the problem of truth and falsehood, of the agreement and disagreement of propositions with reality, of the nature of assertion, assumption, and question, we shall with great advantage look at primitive forms of language in which these forms of thinking appear without the confusing background of highly complicated processes of thought" (Wittgenstein 1958, p. 17) and—we might add—their symbolic and/or formalized representations.

system's state changes—rather than by a *single symbol*—whose structural relations are to depict the system's potential interpretations of its environment. Whereas symbolic representations have to *exclude*, the distributional representations will automatically *include* the (linguistically) structured, pragmatic components which a SCIP system will both, embody and employ as its representational and procedural import to identify and to interpret its environmental structures by means of its own structuredness.

3.3.3 Semiotic Attunement

In a systems theoretic approach, *attunement* replaces the notion of *static* knowledge structures as employed in cognitive information processing models so far, by a *dynamic* conception of structuredness. It defines knowledge as an open, modifiable, and adaptive system whose organization can be conceived as a function of the system's own processing or *knowledge acquisition*. This, however, can only be achieved by allowing *semiotic entities* to have their own (perhaps yet unknown) ontology. It might be not (or not fully) accounted for[25] by predicative and propositional representations or rule-based and truth-functional formats which tacitly make believe that semiotic entities can be characterized and their functions be modeled exclusively by crisp categorial structures and associated processing of well-defined rules for symbol manipulation.

It cannot be overstated, that system analyzers and model constructors dealing with *semiotic* processes in natural language understanding should not rely on the *granular* adequacy of established linguistic categories to represent semiotic entities. Instead, she/he has to make every provision that her/his ideas about the modeling of both, the representation and the processing are not unduly pre-defined by long standing, but possibly inadequate formats. Rule-based models of syntactic processing as well as truth-functional models of (sentence) meaning appear to be as inadequate as predicative and propositional formats of semiotic entity representation and processing. Thus, modeling *semiotic* processes is to find and employ representational formats and algorithmicable procedures which do not prematurely decide and delimit the range of semiotically relevant entities, their representational formats and modes of processing.

One of the advantages which computational models of semiotic processes would have is that the entities considered relevant need not to be defined prior to model construction but will emerge from the very processing which the model realizes or is able to enact. It appears that—if any—this property of models does account for the intrinsic (co- and contextual) constraining of the meaning potentials characteristic of natural language discourse which renders them *semiotic* in a meaning (or function) constituting sense which may also be identified to be the core of *understanding*.

Representing a system's environment (or fragments thereof) in a way, that such representations not only take part in a system's direct (*immediate*) environment (via language texts) but may moreover be understood as virtual in the sense that new (*mediate*) environments (via textual meanings) can also be processed, has been explicitly introduced elsewhere [57] [52] [53]. This view is again dependent on how a system's attunement to these kinds of situated discourse can be tied to the formal concept of *situation* [2] and the analytical notion of *language game* [68] phenomenologically (re)interpreted. The combination of both lends itself easily to operational

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[25] With reference to the *intrinsic* interdependencies of PEIRCE's "tri-relative influence" identified within a *system-environment* processing situation above as "an action, or influence, which is, or involves, a coöperation of *three* subjects, [*sign*, *object*, *interpretant* ...] not being in any way resolvable into actions between pairs." (Peirce 1906, p.282)

extensions in empirical analyses and procedural simulations of processes which may grasp essential parts of meaning constitution realized as process of *understanding*.

4 Fuzzy Linguistics

Recent research findings give rise to some well founded assumptions on whether—and if so, how—*semiotic* models will help to emulate the way structures may emerge from orders of some kind and how these orders relate to or evolve from regularities which multitudes of repeatedly observable entities show. Modeling this kind of *processes* is to define *procedures* for which *algorithms* can be found that at the same time detect the *regularities* concerned and assemble their results to form (intermediate) *representations*. Properties of these procedures may resemble (or can even be identified with) the observable (or experiential) entities which could indeed be responsible for (if not identical with) the usage and emergence of (sign-functional) structures in language understanding systems, both natural and artificial. As more abstract (theoretical) levels of representation for these processes—other than their procedural modeling—are not (yet) available, and as any (formal) means of deriving their possible results—other than by their (operational) enactment—are (still) lacking, it has to be postulated that these processes—independent of all other explanatory paradigms—will not only relate to but produce different representational levels of entity formation. They do so in a way which Marr [26] characterized as being formally controlled or *computable*, which can be modeled procedurally or *algorithmized*, and which may empirically be tested or *implemented*. *Procedural models* of this kind are understood to denote a class of (re)presentational, i.e. modeled (re)constructions of entities whose interpretation is not (yet) tied to an underlying theory which would provide the semantics for the entities (or expressions) that these type of models present. Instanciating their defining *procedures* as implemented algorithms will result in *processes* which produce some (abstract) *structures* whose visualizations can only then be compared to those structures originally observed to hold for and be characteristic of the modeled object.

Structural linguistics has contributed substantially to how language items come about to be employed in communicative discourse the way they are. The fundamental constraints have been identified that control the multi-level combinability and formation of language entities[26] by distinguishing the restrictions on linear aggregation of elements (*syntagmatics*) from restrictions on their selective replacement (*paradigmatics*). Regularities may be described by computational procedures whose varying degrees of combinatorial determinacy will not only detect different patterns of elements' linear distributions but may also be identified with the constraints being applied to constitute the *syntagmata* and *paradigmata* observed. Defining structures of this kind can neither be provided *extensionally* as sets of elements, nor *intensionally* as lists of properties the elements concerned would have to comply with, because both modes would presuppose prior knowledge and understanding of what is to be defined. Not so the *procedural* definition by

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[26] Reference is made to *segmentation* and *classification* of observable strings of entities (on level n) which give rise to identify and segment entities within characteristic cotextual distributions whose classifications allow for these classes to become new entities on level $(n+1)$ string formation which again may be segmented and classified, and so on. Thus, *words* (on level n)—being (granularly) decomposable into *syllables* $(n-1)$, and into *graphemes/phonemes* $(n-2)$ etc.—will compose to aggregated (organized) strings of *phrases* (on level $n+1$), *sentences* $(n+2)$, and *texts* $(n+3)$, etc.

an algorithmic or computational operation whose enactment will instantiate a process in space-time to select the elements concerned according to their structural, i.e. their *syntagmatic* and *paradigmatic* relatedness. Moreover, this mode could provide for the *semioticity* of entities whose vagueness and re-constructive openness will more satisfactorily be accounted for by the dynamism of distributive as opposed to symbolic representational formats. They allow to map structured input data according to its immanent regularities to yield new, structural representations emerging from that computation (as hypothesized by *performative* linguistics and realized in procedural models of *computational semiotics*). Components of these new structures are distributions or vectors of entity-value pairs that depict self-regulatory properties of input entities' structural relatedness, constituting multi-dimensional (metric) space structures (*semiotic spaces*). Their elements may also be interpreted as (labeled) *fuzzy sets* allowing set theoretical operations be exercised on these representations that do not require categorial type (*crisp*) definitions of concept formations. Computation of letter (*morphic*) vectors in *word space*, derived from characteristic n-grams of letter or *grapheme* distributions [39] [38] as well as of word (*semic*) vectors in *semantic space* [42] [43], derived from word type correlations of word token distributions in discourse will serve to illustrate the operational flexibility and granular variability of these representational formats [51] derived from semiotic functions in language performance which traditional linguistic categories fail to identify.

4.1 Word Space

If the basic hypotheses in structural linguistics hold according to which the entity formation in natural language sign systems is governed by the recursively applied principles of *syntagmatic* and *paradigmatic* constraints, then these constraints—restricting theoretical combinability of items to form redundancies in order to make new entities emerge—should be found applicable on the morpho-phonetic and/or the morpho-graphemic level of language to form labeled morphic structures (words), as well as on the word level to form labeled semantic structures (meanings). In what follows, the level of written (or *morpho-graphemic*) sign representation is preferred[27] to that of the sound (or *phono-morphic*) level to illustrate *soft categorizing* in German [39] by *fuzzy linguistic* procedures [55] modeling semiotic functions.

The following notations will be used to outline the computational semiotic approach on the morphic level:

- *n-grams* are n-elementary strings of entities. For $n \geq 2$ they may be analyzed as ordered pairs of adjacent items (letters, graphs, sign-strings, word-strings, etc.) which are the basis of
- *abstractions* over such items which may procedurally be determined as *soft* categorial types (corresponding to characters, graphemes, morphemes, syllables, words, etc.) that have procedurally been defined as
- *fuzzy (sub-)sets* of multi-dimensional sign inventories Z^n with $n > 1$

$$\tilde{X}_n := \{(x, \mu_n(x)) \colon x \in Z^n\} \subseteq Z^n \times [0,1] \tag{1}$$

---

[27] The reason is that VLLC of written language discourse are more easily available than phonetic discourse transcripts, and that the distance between phonemic realization and graphemic representation in German is less than in English or French, where the sound-writing discrepancies are more frequent causing graphemic analyses of these languages to be noisier.

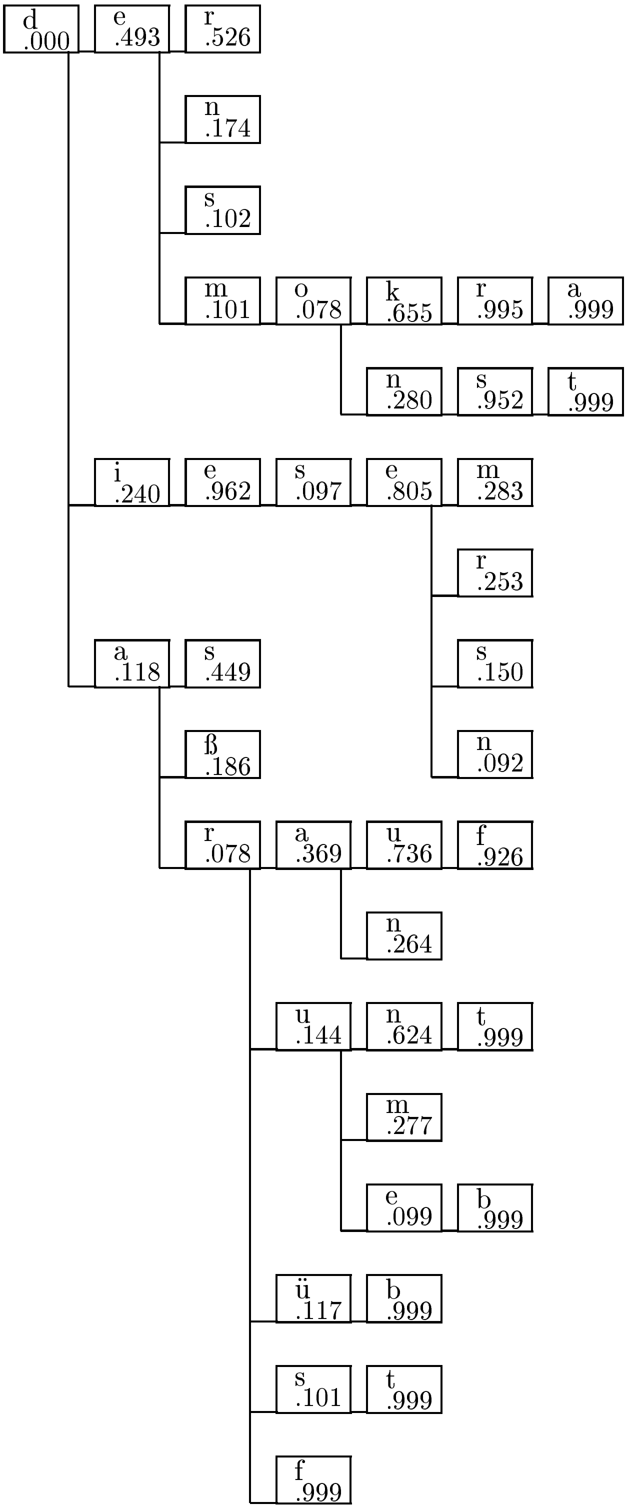

Figure 3: Tree representation of procedural *soft category* $\tilde{\mathbf{d}}$ depicting (part of) the hierarchy of graded letter agglomeration tendencies according to decreasing transitions (in 7-grams) of word beginnings in a sample of the Trier *dpa*-corpus of German newspaper texts. Clearly, word formation of gender casus of definite articles (*der, den, des, dem, die, das*) as well as demonstrative pronouns *diesem, dieser, dieses, diesen*) are revealed (among others) as cotextually determined dispositions which signify the grapheme (letter) **d**.

n- grams	F_n (fact.occurr.)	$T_n = \lvert Z^n \rvert$ (theor.possib.)	$100 \cdot \frac{F_n}{T_n}$ percent	$A_n = m \cdot \lvert F_{n-1} \rvert$ (act.possib.)	$100 \cdot \frac{F_n}{A_n}$ percent
1	31	31	100,000	31	100,000
2	817	961	85,015	961	85,015
3	10.175	29.791	34,154	25.327	40,174
4	54.470	923.521	5,898	315.425	17,268
5	164.045	28.629.151	0,572	1.688.570	9,715
6	357.632	887.503.681	0,040	5.085.395	7,032
7	634.767	27.512.614.111	0,002	11.086.592	5,725
Size of test-corpus :		3.648.326	(signs)	502.587	(words)

Table 1: Grapheme-(letter-)combinatorics with (theoretically and factually) possible and actually occurring *types* of n-grams in German according to a subset of the Trier *dpa*-Corpus

.

Their elements' grades of membership are defined by the membership-function

$$\mu_n \colon Z^n \to [0,1] \tag{2}$$

whose

- *membership-values* $\mu_n(x)$ may be computed inductively as the overall tendency of linear chaining of items in language corpora. For an n-elementary string $x \in Z^n$ be $H_n(x)$ the frequency of x occurring in a corpus. Then, for any
- *bi-gram* $x = (y, z) \in Z^n$, $y \in Z^{n-1}$, $z \in Z$, the coefficient

$$\mu_n(x) = \frac{H_n(x)}{H_{n-1}(y)}. \tag{3}$$

with $Z = \{z_1, \ldots, z_m\}$ will yield for each $y \in Z^{n-1}$ a vector

$$(\mu_n(y, z_1), \ldots, \mu_n(y, z_m))^T \in I\!R^m. \tag{4}$$

The set of all vectors reflect the morphological structure of the corpus analyzed which is the numerically specified basis for the procedural definition of

- *soft categories* which may procedurally be specified by restricting a system of *fuzzy* sub-sets of observed syntagmatic (string) distributions according to their paradigmatic (selective) distributions observed. These may be interpreted to represent *elastic constraints* operating on the language items' chaining tendencies which structure the corresponding corpus.

The presentation of the development of *soft* categories as *elastic constraints* (operating on different levels) can be simplified by their formal introduction as (n-ary) *fuzzy* relations and their corresponding numerical formats of transition matrices (of higher orders).

For written German discourse analyzed on type-setting level with m discernible types of signs (letters) and maximum lengths n of strings, there are quite a number of theoretically possible (*Tab.* 1, col. $T_n = Z^n$) crisp n-ary relations, i.e.

$$
\begin{array}{rcll}
Z = T_1 & = & \{x_1 & : x_1 \in Z\} \\
T_2 & = & \{(x_1, x_2) & : x_1, x_2 \in Z\} \\
T_3 & = & \{(x_1, x_2, x_3) & : x_1, x_2, x_3 \in Z\} \\
\vdots & & \vdots & \vdots \\
T_{n-1} & = & \{(x_1, \ldots, x_{n-1}) & : x_1, \ldots, x_n \in Z\} \\
T_n & = & \{(x_1, \ldots, x_n & : x_1, \ldots, x_n \in Z\}.
\end{array}
$$

Out of these, however, only those have to be computed which are not only actually possible (col. A_n) but which have indeed been observed to factually occur, i.e. $F_n \subseteq F_{n-1} \times Z$ (*Tab.* 1, col. F_n), i.e.

$$
\begin{array}{rll}
Z = F_1 \subseteq & \{x_1 & : x_1 \in Z\} \\
F_2 \subseteq & \{(x_1, x_2) & : x_1 \in F_1, x_2 \in Z\} \\
F_3 \subseteq & \{(x_1, x_2, x_3) & : (x_1, x_2) \in F_2, x_3 \in Z\} \\
\vdots & \vdots & \vdots \\
F_{n-1} \subseteq & \{(x_1, \ldots, x_{n-1}) & : (x_1, \ldots, x_{n-2}) \in F_{n-2}, x_{n-1} \in Z\} \\
F_n \subseteq & \{(x_1, \ldots, x_n) & : (x_1, \ldots, x_{n-1}) \in F_{n-1}, x_n \in Z\}.
\end{array}
$$

The *fuzzy* relational modeling according to (3) and (2) shows that even for higher n only *bigrams* have to be traced and computed due the $(n-1)$-ary relations computed on the previous level of representation. It is this principle of procedural *self-similarity* of n-ary agglomerative steps which allows for the tree-like *trie*[28] representation of entities that are labeled (by soft categorial n-relative letter transitions) and are an outcome of procedural constraints (over n levels of processing) which produce a dynamically structured system of fuzzy relations that depicts the overall transition tendencies of a grapheme sign. For the letter d this *soft grapheme* structure is given in *Fig.* 3 illustrating sub-regularities of morphic word formation.

4.2 Semantic Hyperspace

Again following the procedural approach in *computational semiotics*, the reconstruction of linguistic functions or meanings of words is based upon the fundamental distinction of natural language items' agglomerative or *syntagmatic* and selective or *paradigmatic* relatedness. Consequently, the core of the analytical and/or representational formalism can be characterized as a two-level process of abstraction (called α- and δ-abstraction) on the set of *fuzzy* subsets of the vocabulary—providing the word-types' usage regularities or *corpus points*—and on the set of *fuzzy* subsets of these—providing the corresponding *meaning points* as a function of those word-types which are being instantiated by word-tokens as employed in *pragmatically homogeneous* corpora of natural language texts.

4.2.1 Quantitative Linguistic Data

The basically descriptive statistics used to grasp these relations on the level of *words* in discourse are centered around a correlational measure (9) to specify intensities of co-occurring lexical items

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[28] This neologism coined by KNUTH (1973) [22] refers to a graph representation of an organizational structure for efficient storage and retrieval of linearly related entities. But whereas KNUTH's *trie* structures are based upon frequencies of entity occurrences, our *soft category* representations of graphemes are based upon relative frequencies of n-agglomerative entity transitions computed separately on each level n for all letters observed.

in texts, and a measure of similarity (or rather, dissimilarity) (13) to specify differing distributions of correlation values. Simultaneously, these measures may be interpreted semiotically as providing for set theoretical constraints or formal mappings α (11) and δ (15) which model the meanings of words as a function of these words' differences in usage regularities.

As a *first* mapping function α allows to compute the relational interdependence of any two lexical items from their textual frequencies. For any pragmatically homogeneous corpus

$$K = \{k_t\} \ ; \ \ t = 1, \ldots, T \tag{5}$$

of texts k_t, having an overall length

$$L = \sum_{t=1}^{T} l_t \ ; \ \ 1 \leq l_t \leq L \tag{6}$$

measured by the number l_t of word-tokens per text, and a vocabulary

$$V = \{x_n\} \ ; \ \ n = 1, \ldots, i, j, \ldots, N \tag{7}$$

of N word-types x_n of different identity i, j whose frequencies are denoted by

$$H_i = \sum_{t=1}^{T} h_{it} \ ; \ \ 0 \leq h_{it} \leq H_i \tag{8}$$

the modified correlation-coefficient $\alpha_{i,j}$ allows to express pairwise relatedness of word-types $(x_i, x_j) \in V \times V$ by numerical values ranging from -1 to $+1$. These are calculated from co-occurring word-token frequencies comparing their *observed* h_{it}, against their *expected* h^*_{it} values for any text t in the following way

$$\alpha(x_i, x_j) \ = \ \frac{\sum_{t=1}^{T}(h_{it} - h^*_{it})(h_{jt} - h^*_{jt})}{\left(\sum_{t=1}^{T}(h_{it} - h^*_{it})^2 \sum_{t=1}^{T}(h_{jt} - h^*_{jt})^2\right)^{\frac{1}{2}}} \ ; \ -1 \leq \alpha(x_i, x_j) \leq +1 \tag{9}$$

$$\text{where } h^*_{it} = \frac{H_i}{L} l_t \ \text{ and } \ h^*_{jt} = \frac{H_j}{L} l_t .$$

Evidently, as normalized by the denominator in this expression, pairs of items (x_i, x_j) which frequently either co-occur in, or are both absent from, a relatively graded majority of texts will positively be correlated $\alpha(x_i, x_j) \leq +1$ and called *affined*, those pairs of which only one (and not the other) item occurs frequently will negatively be correlated $\alpha(x_I, x_j) \geq -1$ and hence called *repugnant*.

As a fuzzy binary relation,

$$\tilde{\alpha} \ : \ V \times V \rightarrow I \tag{10}$$

can be conditioned on $x_n \in V$ which yields a crisp mapping

$$\tilde{\alpha} \mid x_n \ : \ V \rightarrow C \ ; \ \{y_n\} =: C \tag{11}$$

where the tuples $\langle(x_{n,1}, \tilde{\alpha}(n, 1)), \ldots, (x_{n,N}, \tilde{\alpha}(n, N))\rangle$ represent the numerically specified, *syntagmatic* usage regularities that have been observed for each word-type x_i against all other $x_n \in V$ and can therefore be abstracted over one of the components in each ordered pair. This so-called *α-abstraction* (*Tab.* 2) defines an element $y_i \in C$

$$x_i(\tilde{\alpha}(i, 1), \ldots, \tilde{\alpha}(i, N)) =: y_i \in C \tag{12}$$

Hence, the regularities of usage of any lexical item will be determined by the tuple of its *affinity/repugnancy*-values towards each other item of the vocabulary. As these may be interpreted as coordinate values, the tuples can be represented by points y_n in a vector space C spanned by the number of axes N each of which corresponds to an entry x_n in the vocabulary V.

Considering C a representational structure of abstract entities y_n constituted by *syntagmatic* regularities of word-token occurrences in *pragmatically homogeneous* discourse, then the similarities and/or dissimilarities between these abstract entities will capture the corresponding word-types' *paradigmatic* regularities. These can be modeled by the *δ-abstraction* which is based on the numerically specified evaluation of differences between any two of such points $y_i, y_j \in C$. These point representations will be the more adjacent to each other, the less the usages (*tokens*) of their corresponding lexical items $x_i, x_j \in V$ (*types*) differ. The differences may be calculated by a distance measure δ of, say, EUCLIDian metric.

$$\delta(y_i, y_j) \; = \; \left(\sum_{n=1}^{N} (\alpha(x_i, x_n) - \alpha(x_j, x_n))^2 \right)^{\frac{1}{2}} \; ; \; 0 \leq \delta(y_i, y_j) \leq 2\sqrt{n} \tag{13}$$

Thus, δ will serve as a *second* mapping function to represent any item's differences of usage regularities measured against those of all other items. As a fuzzy binary relation, also

$$\tilde{\delta} \; : \; C \times C \to I \tag{14}$$

can be conditioned on $y_n \in C$ which again yields a crisp mapping

$$\tilde{\delta} \mid y_n \; : \; C \to S; \; \{z_n\} =: S \tag{15}$$

where the tuples $\langle (y_{n,1}, \tilde{\delta}(n,1)), \ldots, (y_{n,N}\tilde{\delta}(n,N)) \rangle$ represents the numerically specified *paradigmatic* structure that can be derived for each *syntagmatic* usage regularity y_j against all other $y_n \in C$. These distance values can therefore be abstracted again analogous to (12), this time, however, over the other of the components in each ordered pair. The so-called *δ-abstraction* (*Tab.* 2) defines an element $z_j \in S$ named *meaning point* in S by

$$y_j(\tilde{\delta}(j,1), \ldots, \tilde{\delta}(j,N)) =: z_j \in S \tag{16}$$

By identifying $z_n \in S$ with the numerically specified elements of potential paradigms, the set of possible combinations $S \times S$ may structurally be constrained and evaluated without (direct or indirect) recourse to any pre-existent external world. Introducing a EUCLIDian metric

$$\zeta \; : \; S \times S \to I \tag{17}$$

the hyper-structure $\langle S, \zeta \rangle$ or *semantic hyperspace* (SHS) is declared, constituting the system of *meaning points* as an empirically grounded and functionally derived representation of a lexically labeled knowledge structure.

mufuzz1.1

4.2.2 Semiotic Functions

As a result of the two-stage *consecutive* mappings any meaning point's position in $\langle S, \zeta \rangle$ is determined by all the differences (δ- or distance-values) of all regularities of usage (α- or correlation-values) each lexical item shows against all others in the discourse analyzed. Without recurring to any investigator's or his test-persons' word or world knowledge (*semantic competence*), but solely on the basis of usage regularities of lexical items in discourse (*communicative performance*),

$$\begin{array}{ccccc}
 & \alpha\text{-abstraction} & & \delta\text{-abstraction} & \\
V \times V & \Downarrow & C \times C & \Downarrow & S \times S \\
\begin{array}{c|ccc} \tilde{\alpha} & x_1 & \dots & x_N \\ \hline x_1 & \alpha_{11} & \dots & \alpha_{1N} \\ \vdots & \vdots & \ddots & \vdots \\ x_N & \alpha_{N1} & \dots & \alpha_{NN} \end{array} & \xrightarrow{\tilde{\alpha} \mid x_i} & \begin{array}{c|ccc} \tilde{\delta} & y_1 & \dots & y_N \\ \hline y_1 & \delta_{11} & \dots & \delta_{1N} \\ \vdots & \vdots & \ddots & \vdots \\ y_N & \delta_{N1} & \dots & \delta_{NN} \end{array} & \xrightarrow{\tilde{\delta} \mid y_j} & \begin{array}{c|ccc} \zeta & z_1 & \dots & z_N \\ \hline z_1 & \zeta_{11} & \dots & \zeta_{1N} \\ \vdots & \vdots & \ddots & \vdots \\ z_N & \zeta_{N1} & \dots & \zeta_{NN} \end{array} \\
 & \Uparrow & & \Uparrow & \\
 & \textit{Syntagmatic} & & \textit{Paradigmatic} & \\
 & & \textit{Constraints} & &
\end{array}$$

Table 2: Formalizing (*syntagmatic/paradigmatic*) constraints by consecutive (α- and δ-) abstractions over usage regularities of items x_n and their differences y_n to form meaning representations z_n respectively.

$$\begin{tikzcd}
 & C \arrow[loop above, "\tilde{\delta}"] \arrow[dr, "\tilde{\delta} | y_j"] & \\
V \arrow[loop left, "\tilde{\alpha}"] \arrow[ur, "\tilde{\alpha} | x_i"] \arrow[rr, "\tilde{\delta} | y_n \circ \tilde{\alpha} | x_n"'] & & S \arrow[loop right, "\zeta"]
\end{tikzcd}$$

Figure 4: Fuzzy mapping relations $\tilde{\alpha}$ and $\tilde{\delta}$ between the structured sets of vocabulary items $x_n \in V$, of corpus points $y_n \in C$, and of meaning points $z_n \in S$.

some global structure is derived procedurally from natural language discourse by computational processes which construct and simultaneously identify topological positions of meaning points $z_i \in \langle S, \zeta \rangle$ as meaning representations of corresponding vocabulary items $x_i \in V$. This consecutive mapping function is called *semiotic* because it *(re)constructs* part of the process of natural language *understanding* as a function of language items' differences of usage regularities as observed and made measurable in discourse whose *meaning* emerges from that mapping and is depicted and represented in the resultant topological structure of SHS. The *semiotic* mapping can formally be stated as a category of morphisms [65] or a set theoretical composition of two restricted (fuzzy) relations $\tilde{\delta} \mid y$ and $\tilde{\alpha} \mid x$ (*Fig.* 4). Thus, the consecutive application of (11) on input texts and (15) on its output data allows to model the meanings of words as a fuzzy set theoretical *composition*, a category of *semiotic morphisms*, or computationally as a two-level function of differences (*paradigmatic* selection) of usage regularities (*syntagmatic* aggregation) as schematized in *Tab.* 2.

5 (Re)Constructing Reference

Processing natural language texts the way these algorithms do would appear to grasp some relevant portions of the ability to recognize and represent and to employ and modify internally the structural information available and accessible external to a system which is capable of processing language regularities. A *semiotic cognitive information processing* (SCIP) system endowed with these capabilities and performing likewise in building up an internal representation of its processing results would consequently be said to have constituted some—however shallow—text *understanding*. The problem is, whether (and if so, how) the contents of what such a system is said to have understood can be tested, i.e. made accessible other than by the language texts in question and/or without committing to a particular semantics whose presuppositions would inevitably determine all possible interpretations.

So far, a system of word meanings (*lexical knowledge*) has been modeled in $\langle S, \zeta \rangle$ as a relational data structure whose linguistically labeled elements (*meaning points*) and their mutual distances (*meaning differences*) form a system of potential *stereotypes*. Although on first sight these points appear to be *symbolic* meaning representations, it is worth mentioning here again that in fact each such point is determined by a *fuzzy set* or *value distribution* of pairs of word types associated with numerical values. Meaning representation via points (or vectors) in *semantic hyper space* (SHS) is a matter of the position a point (or the direction a vector) takes among others, and it is this position (or direction) which interprets the lexical label attached to it, not vice versa. Therefore, based upon SHS-structure as computed from the items' usages in the discourse analyzed, the *meaning* of a lexical item may be described either as a fuzzy subset of the vocabulary, or as a meaning point's vector, or as a meaning point's topological environment delimiting the central point's position indirectly as its *stereotype* [36] [49].

This variability of representational formats complies with the *semiotic* notion of *understanding* and *meaning constitution* according to which the SHS may be considered the core or base model of a multi-level conceptual knowledge representation system [37]. Essentially, it separates the format of a basic (stereotype) word meaning or concept representation from its latent relational forms of organization for particular cognitive purposes. Whereas the former may be thought of as a comparatively stable (or *long-term*), though dynamic topologically structured (associative) memory, the latter can be characterized as a collection of structuring procedures which (re)organize the memory data according to cognitive tasks to be solved under situational (or *short-term*) conditions[29].

As we have separated cognitive processes from their resultant structures above, so may we distinguish here between the short-term *process* in a situational embedding (employment or activation) and its long-term *structure* as an addressable representation of knowledge (stereotype or concept) with the semiotic implication that the structures depend on the processes and vice versa to let addressable representations emerge and cognitive processes be enacted. Thus, the duality of the inner-outer distinction or the system-environment opposition may be mediated (or even suspended) by processes operating on some supposedly common, basal representational

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[29] This notion not only corroborates but extends ideas expressed within the theories of *priming* and *spreading activation* [25] now allowing e.g. for the *dynamic* and task-oriented generation of paths (along which activation might spread) without being confined anymore to pre-defined static relations. The situational generation of these paths actually allows to model *priming* as a *realized* cognitive function rather than a *simulation* of processes related with it in the past.

structures[30] whose efficient (re)organization can be modeled only procedurally. What appears disturbing as a consequence of the process-result distinction in the first instance is that the procedural models of cognitive processes—not the processes themselves—produce accessible results in representational structures which—depending on the way they are addressed—will result in the (more or less *subjective*) internal or *endo*-view the system develops, and in a (more or less *objective*) external or *exo*-view of the surrounding environment that constitutes the system's *reality* by virtue of its *endo*-structure[31]. However, on second thought the computational semiotician finds herself/himself engaged in a constitutive part of the very process of meaning constitution (semiotic function) which she/he was trying to model as a process of knowledge-based information processing (cognitive function). Apparently, *realizational* models of semiotic aspects of cognition will produce emergent representational results which are open to perspectival (*endo*/*exo*) interpretation whereas *simulative* models will not.

To find out (and preferably be able to test) what of the *structural* information inherent in natural language discourse—defined and structured by the text analytical, computational processes described above—might be involved in mediating or constituting that duality, an experimental setting has been designed. It is based on the assumption that some representational level or core structure—similar to the one modeled by SHS—ought to be postulated in order to be considered a common base for different notions of meaning or content of natural language expressions developed by theories of *referential* and *situational* semantics as well as some *structural* or *stereotype* meaning theories.

5.1 Experimental Testing

For the purpose of testing *semiotic* processes of meaning constitution, situational complexities have to be reduced by abstracting away irrelevant components, hopefully without oversimplifying the issue and trivializing the problem. Therefore, the propositional form of natural language predication—undoubtedly the common basis of traditional meaning theories—will not be done away with or neglected. Instead, it shall be employed to construct and generate in a controlled way the natural language material which is to be used for the training and test of the system, not however, will the propositional structure determine the way this training material is to be processed in the test. To have semantically well defined and truth conditionally clear language expressions of propositions denoting referentially doubtless facts in a specified situation would appear to be a necessary condition for a test (or *experimentum crucis*) to show whether or not a non-propositional processing of strings of propositions in pragmatically homogeneous texts can result in some structure either identical, or at least similar, to the facts described in these texts, and/or related in some regular way to the denoted structures referred to by these texts.

To give a general view of the approach first, the experimental setting is imagined to consist of an artificial mobile *system* in a two dimensional *environment* with some objects at certain places which are to be identified[32]. The system's channels of perception allowing to form its

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[30] Representational formats will be called *basal* if they can provide a frame for the formal unification of categorial-type, concept-hierarchical, truth-functional, propositional, phrasal, or whatever other intermediate representations.

[31] It appears that what PATTEE (1995) named *semantic closure* and characterized as a specific relation between both the material (performative) and the symbolic (representational) aspects of any organism's behavior is another perspectival view on this phenomenon.

[32] As will become clear in what follows, this identification concerns the *places* so far and does not (yet) apply to

own or *endo*-view of its surroundings are extremely limited, and its ability to act (and react) is heavily restricted compared to natural or living information processing systems. What makes such an abstract system a *semiotic* one is that—whatever it might gather from its environment—it will not be the result of some decoding processes which would necessarily call for that code to be known to the system. Instead, any result will be constituted according to the system's (co- and contextually restricted) susceptibility and processing capabilities to (re)organize the environmental data and to (re)present the results in some dynamic structure which determines the system's knowledge (susceptibility), learning (change) and understanding (representation).

This postulate, obviously, rules out immediately any of the traditional approaches to cognitive modeling. They do not see the need of an *endo-/exo*-differentiation and are satisfied instead with well established formalisms (in syntax, semantics, predicate logics) which not only allow to distinguish, describe, and represent different levels of natural language structures but apparently also determine and control the processing of what these levels are meant to model. Consequently, knowledge based representations were conceived corresponding to the cognitive processes believed to operate on them, depending on and according to the convictions held about the way natural language expressions are to be analyzed and interpreted, and not as they might be understood by humans. It is still difficult to accept that the syntactic and semantic analysis (*parsing* and *interpretation*) of natural language expressions is more of a fault tracing and correcting machinery than a model of default mechanisms underlying natural language understanding[33]. This is one of the reasons why cognitive models in linguistics appear to have persistently narrowed the general (and *semiotic*) scope of natural languages *understanding* to become identified with structure *processing*. Accordingly, language processing appeared to be reducible to a problem of inventing symbolic representations for (both, world and linguistic) knowledge structures which *rules* of formal syntax and semantics could be made to operate on (*memory*). Thus, textual discourse is identified solely with propositional function ascribing to it syntactic structures of sentences whose truth-conditional interpretation is determined by a referential semantics. This, in turn, seems to allow for the definition of predicate meanings according to properties believed to be observed, recognized, identified, and named in the world around and external to the cognitive systems. However, to follow this line of modeling is to favor a very particularized understanding of natural *language understanding* which is hardly tenable. It also appears scarcely convincing why some (admittedly well understood) formalisms representing certain functional results on different levels of (more or less arbitrary) abstractions should also provide the only levels and modules to study and investigate the (as yet enigmatic) processes related to (or even underlying) these or other cognitive functions in language understanding by humans. It is this governing hypothesis of the structure-function relation—purportedly clear-cut and in no need of representational scrutiny—underlying models of language processing in cognitive linguistics which is questioned.

The experimental setting developed to allow for such a test of language understanding without committing to the semiotically unwarranted presuppositions of sentencial and truth-conditional reconstructions of language processing, is still tentative. It hinges on the assumption that cognitive information processing will both operate on and produce structures as a condition for and/or

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the *objects*.

[33] The difference may be seen as an analogue to the phenomenological distinction made by existential philosophy between *efficient modes* of immediate understanding (Dasein) and its *deficient modes* in need of object constitutional explication (Welt).

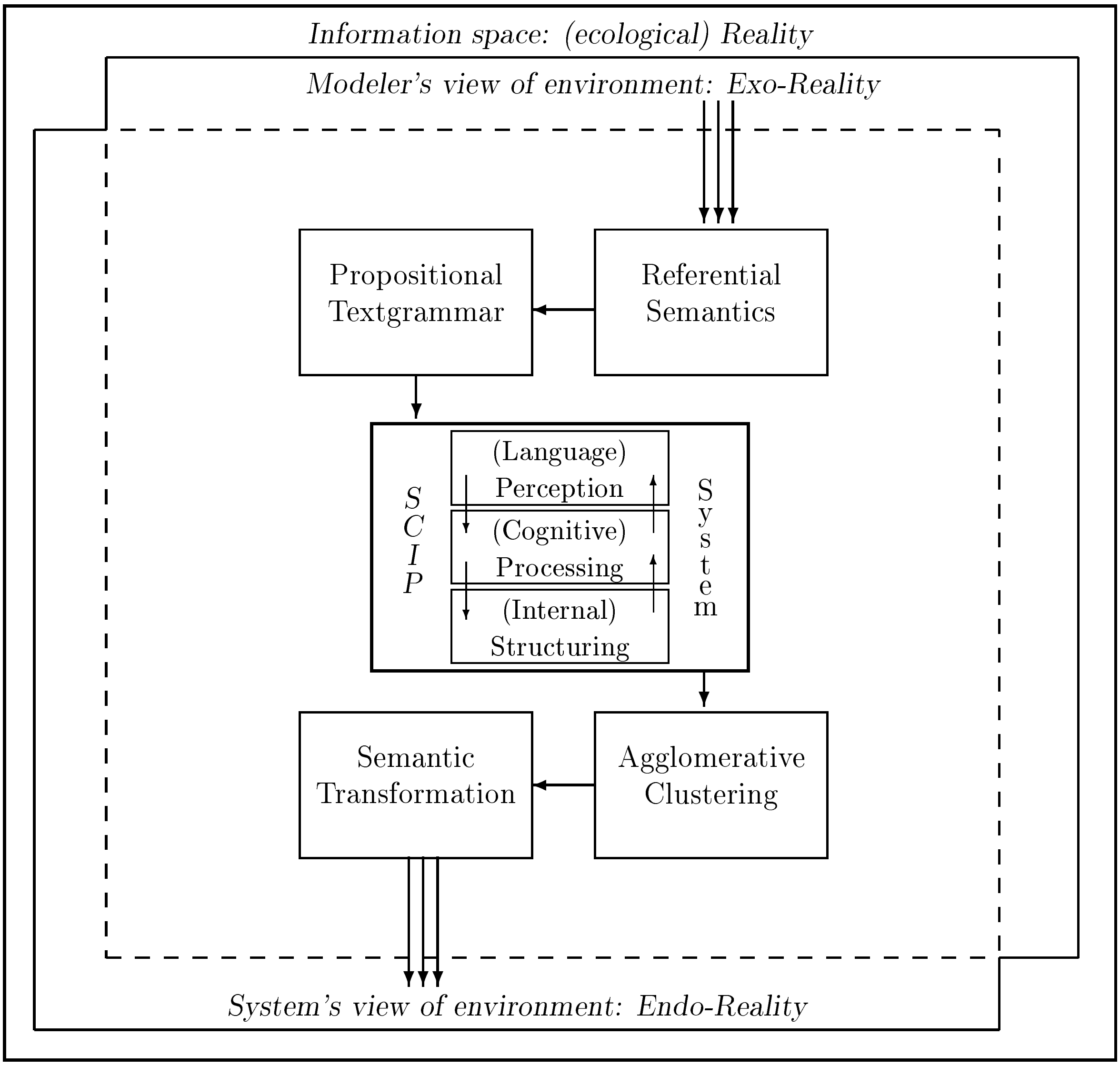

Figure 5: Situational setting of a SCIP system within an environment which is defined to allow for the system's view of it (*Endo-Reality*) to differ from what the external observer's view (*Exo-Reality*) might be. This is achieved by keeping the system's (non-propositional) faculties of language processing strictly apart from the (propositional) way the language data is generated as a truth-functional correct textual protocol description of system-environment relations serving as their *structural coupling*. Note, that *grammar* (lexicon, syntax) and *semantics* are not part of the system's language processing (linguistic knowledge), and that also the visualization modules (cluster analysis, semantic transformation) applied to the systems internal representation (knowledge or understanding) are external to the system's semiotic processing. These components are introduced exclusively to formally specify and control the system's environment as its language input *and* to allow for a semantic interpretation and visualized image of the internal structure of the system's acquired knowledge at a time.

a result of such processing. These *structures* have to have some space-time extension, i.e. are in principle observable apart from and independent of being processed cognitively. The *processes* operating on and modifying them can also in principle be dealt with independent of their temporal duration by *procedures* which can be defined as processes abstracted from their temporality. *Procedures* can be represented formally, their notational format be parsed and checked for correctness, their expressions be interpreted or compiled for execution and—provided a suitable automaton is available—become initial for the enactment of *processes* in time again, having not only a certain duration but also the effect of operating on and modifying *structures* which in fact—not only in principle—are observable as (input-output related) changes.

This two-sided independence facilitates procedural cognitive models to relate *structured language expressions* which can be analyzed (or observed) without being understood, to *language understanding processes* which can be conceived (as procedures) being abstracted from their temporal duration. It appears, that by this move procedures and algorithms found to model some aspects of cognitive information processing for language comprehension can be tested against—not on the grounds of—any accepted, well defined model of cognitive (language) understanding. And test results would have to be considered positive for all cases in which the contents of the same language expressions is represented or depicted in either identical (or at least similar) results for both models.

Thus, to enable an inter-subjective scrutiny, the (unknown) results of an abstract artificial (SCIP) system's (well known) processing of natural language discourse is compared to the (well known) traditional (LP and CL)[34] interpretations of the (unknown) processes of natural language meaning constitution[35]. Therefore, the propositional form of natural language predication, will be used here only to control both the format and the contents of the natural language training material, not, however, to determine the way it is processed to model *understanding*.

5.2 Situational Conditions

For the purpose of testing *semiotic* processes, their situational complexity has been said to be in need of an abstractive reduction that does not oversimplify the issue or trivialize the problem. Trying to achieve this, situational parameters have to be determined guaranteeing

- ▷ that the three main components of the experimental setting, the *system*, the *environment*, and the *discourse* are specified by sets of conditioning properties. These define the SCIP system by way of a set of (partly procedural) parameters like *orientation, mobility, perception, processing* (*Tab.* 3). The SCIP environment is defined as a set of formal entities like *reference plane, objects, grid, direction, location* (*Tab.* 4). And the SCIP discourse material coupling system and environment (*structural coupling*) as language mediation is structured first by a number of whole-part related (*granular*) entities like *corpus, text, sentence, word* (*Tab.* 5) of which *sentence* and *text* require further defining restrictions in order to become specified by a formal *syntax* (*Tab.* 6) and referential *semantics* (*Tab.* 7);
- ▷ that the system's environmental data is provided by a corpus of (natural language) texts comprising correct expressions of true propositions denoting how system-positions relate to

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[34] i.e. Linguistics proper (LP) and cognitive/computational linguistics (CL)

[35] The concept of *knowledge* underlying the employment of the adjectival terms here is meant to be understood in the sense that "*known*" generally refers to having some well established (however controversial experiential, scientific, inter-subjective) *models* to deal with, whereas "*unknown*" refers to the lack of such models.

SCIP **System** :	$\{\mathcal{O},\mathcal{M},\mathcal{P},\mathcal{C},\mathcal{A}\}$
Orientation :	$\mathcal{O} := \{\vec{N} = (0,1), \vec{E} = (1,0), \vec{S} = (0,-1), \vec{W} = (-1,0)\}$
Mobility :	$\mathcal{M} := \{k(0,1), k(1,1), k(1,0), k(1,-1), k(0,-1), k(-1,-1), k(-1,0), k(-1,1)$
(*pace*)	$: k = 1\}$
LanPerception :	$\mathcal{P} := \{K := \{k_t\}, L := \sum_{t=1}^{T} l_t, V := \{x_i\}, H_i := \sum_{t=1}^{T} h_{it}$
	$: i = 1, \ldots, j, \ldots, N\}$
CogProcessing :	$\mathcal{C} := \{\alpha,\ \delta,\ \zeta,\ \ldots\};\ \mathcal{A} := \{\tilde{\alpha} \mid x,\ \tilde{\delta} \mid y,\ \ldots\}$
Semantics :	**none**
Syntax :	**none**

Table 3: Collection of SCIP systems' formal properties. Note, that there is neither syntactical, nor semantic knowledge defined as provided for the system.

SCIP **Environment** :	$\{\mathcal{R}_{\mathrm{E}}, \mathcal{R}_{\mathrm{O}}, \mathcal{R}_{\mathrm{R}}, \mathcal{D}, \ell_{\mathcal{R}}\}$
Reference plane :	$\mathcal{R}_{\mathrm{E}} := \{P_{n,m} : \exists R_{n,m} \in \mathcal{R}_{\mathrm{R}}(n_0, m_0, g), P_{n,m} \in R_{n,m}\}$
Reference objects :	$\mathcal{R}_{\mathrm{O}} := \{\square,\ \triangle,\ \ldots\ \}$
Reference grid :	$\mathcal{R}_{\mathrm{R}}(n_0, m_0, g) := \{\mathrm{R}_{n,m} = [(n-1)g, ng] \times [(m-1)g, mg],$
	$1 \leq n \leq n_0\,, 1 \leq m \leq m_0\,, g > 0\}$
Directions :	$\mathcal{D} := \{\vec{N} := (0,1), \vec{O} := (1,0), \vec{S} := (0,-1), \vec{W} := (-1,0)\}$
Object location :	$\ell_{\mathcal{R}} : \mathcal{R}_{\mathrm{O}} \longrightarrow \mathcal{R}_{\mathrm{E}}$

Table 4: Collection of SCIP environments' formal properties.

SCIP **Structural Coupling**:

Word: the entity (sign) identified as vocabulary element (type) whose occurrences in (linear) sets of entities (tokens) are countable;

Sentence: the (non-empty, linear) set of words to form a correct expression of a true proposition denoting a relation of system-position (SP) and object-location (OL);

Text: the (non-empty, linear) set of sentences with identical pairs of core-predicates denoting SP-OL relations resulting from linear movement of the system to directly adjacent positions;

Corpus: the (non-empty) set of texts comprising descriptions of (any or all) factually possible SP-OL relations within a specified systemic and environmental setting.

Table 5: Collection of conceptual restrictions that define language material entities constituting the coupling of SCIP system and SCIP environment structurally.

object-locations (SP-OL relations for short). These material world relations are described according to the formally specified syntax and semantics (representing the *exo*-view or *described situations*), and

▷ that the system's internal picture of its surroundings (representing the *endo*-view or *discourse situations*) is to be derived from this language environment other than by way of propositional reconstruction, i.e. without syntactic parsing and semantic interpretation of sentence and text structures.

Consequently, the *exo*-knowledge allowing the designers of the experimental setting to control the *propositional* encoding and decoding of environmental information in texts which the system—

$$
\begin{array}{rl}
\mathrm{T(ext)} := & \{S_i \mid S_i \longrightarrow S_{i+1} : \mathcal{M} \wedge \{KP_1, KP_2\} \in S_i \wedge \{KP_1, KP_2\} \in S_{i+1} \\
 & \qquad\qquad\qquad\qquad\qquad \wedge\ \forall\ KP_j\ \in\ S_i \cup S_{i+1}; j = 1,2; \quad i = 1, \ldots, I\} \\
\mathcal{M} := & \{k(0,1), k(1,1), k(1,0), k(1,-1), k(0,-1), k(-1,-1), k(-1,0), k(-1,1) \\
 & :\ k = 1\} \\
\mathrm{S}_i \longrightarrow & \mathrm{NP} \quad \mathrm{VP} \\
\mathrm{NP} \longrightarrow & \mathrm{N} \\
\mathrm{VP} \longrightarrow & \mathrm{V} \quad \mathrm{PP} \\
\mathrm{PP} \longrightarrow & \mathrm{HP} \quad \mathrm{KP} \\
\mathrm{N} \longrightarrow & \textit{a}\ \langle\ \textit{triangle} \mid \textit{square}\ \rangle \\
\mathrm{V} \longrightarrow & \textit{lies} \\
\mathrm{HP} \longrightarrow & \langle\ \textit{extremely} \mid \textit{very} \mid \textit{rather}\ \rangle \langle\ \textit{near} \mid \textit{far}\ \rangle \\
\mathrm{KP} \longrightarrow & \langle\ \textit{on the left} \mid \textit{on the right}\ \rangle \mid \langle\ \textit{in front} \mid \textit{behind}\ \rangle
\end{array}
$$

Table 6: Syntax of text grammar for the generation of strings of correct descriptions of possible SP-OL (system-position and object-location) relations.

being placed in that environment as specified in such a way—would have to process, had to be kept strictly apart from the SCIP system's *endo*-capacities into which it was definitely not to be included. Thus, the system's own *non-propositional* processing would have to allow for some results which—as the system's *internal* representation—would not be interpretable as mere repetitious reproductions or as an application of knowledge structures made available to it *externally*. Instead, it would have to have in principle a chance to be different from—however comparable to—the *exo*-view of its environment as specified by propositional descriptions. This is tantamount to the quest for a representation whose format allows visualization of *endo*-computed adjacencies and comparison to *exo*-defined relations.

5.3 Processes and Results

The procedures enabling *semiotic processing* operate in a situational setting that consists of a two dimensional environment with the objects of a triangle and a square at certain places (*Fig.* 6 left part). A SCIP system will have to identify them on the grounds of sets of natural language expressions it is exposed to which describe SP-OL relations correctly. Although the SCIP-system's perception is limited to its (formal) language processing capabilities (which do not entail any knowledge of syntax or of semantics) and as its ability to act (and react) is restricted to stepwise linear movement and global processing of discourse information, it will come up with some acquired internally represented structure corresponding vaguely to its external environment (*Fig.* 6 right part) when visualized to allow for a comparison.

What makes the processing of such a system *semiotic* is that it will not apply any (symbolically) coded knowledge (of linguistic structures and their semantics) during that processing, but—as such knowledge is not made available to it—will instead be confined to its own computing capabilities in (re)organizing the environmental data and (re)presenting its results.

The example lay-out is illustrated by the object-*locations* in the reference plane (*Fig.* 6 left part). It provided the base for the cognitive situations to be described which consisted in all possible system-*positions* (SP) and *orientations* $\mathcal{O}$ relative to the two object-*locations* (OL). The language expressions describing these relations were generated automatically for given OL and all possible SP according to the formal syntax (*Tab.* 6) and semantics (*Tab.* 7) specified above. The resulting corpus comprises some 12 432 word tokens of 26 word types in 2 483 sentences and 684 texts. This training set of generated language material was then exposed to the SCIP system which perceived it as environmental data to be processed according to its specified faculties (*Tab.* 3), namely *language perception* $\mathcal{P}$, i.e. identifying and counting string entities of different types—according to (5), (6), (7), and (8)—and *cognitive processing* $\mathcal{C}$, i.e. computation and organization—according to (9), (10), and (11) as well as (13), (14), and (15)—and *abstracting* $\mathcal{A}$, i.e. formation and representation of new entities—according to (12) and (16)—as introduced above.

In the course of processing, the composite morphisms (*Fig.* 4) as summarized in the two-level mapping abstractions (*Tab.* 2) result in the *semantic hyper space* (SHS). Its intrinsic structure reveals some properties which can be made visible in a three stage process:

- ▷ first, applying methods of average linkage cluster analysis allows to identify (*Fig.* 7) structurally adjacent word types (like entity labels of object and predicate candidates) [45] [54] comparable to KOHONEN self-organizing semantic maps [24] [58] which yield comparable though internally less structured results;
- ▷ second, their *numerical* hedge interpretation provides the SP-OL distance values whose *directional* core interpretations determine virtual regions of object locations relative to the system's

Core-predicates (KP)
as > and < relations of system positions x, y and object locations n, m (0-coordinates being down left) for all orientations N, E, S, W of the system

NORTH x, y	*in front*	*behind*
on the left	>m, <n	>m, >n
on the right	<m, <n	>m, <n

EAST x, y	*in front*	*behind*
on the left	<m, <n	>m, <n
on the right	<m, >n	>m, >n

SOUTH x, y	*in front*	*behind*
on the left	<m, >n	<m, <n
on the right	>m, >n	<m, >n

WEST x, y	*in front*	*behind*
on the left	>m, >n	<m, >n
on the right	>m, <n	<m, <n

Hedge-predicates (HP)
as distances of SP-OL (*crisp-* and *fuzzy-* interpretations): by number of grid-points ($|\ x - \mathrm{n}\ |$ and $|\ y - \mathrm{m}\ |$)

Crisp 1.0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
extremely near	1	1	0	0	0	0	0	0	0	0
very near	0	0	1	1	0	0	0	0	0	0
rather near	0	0	0	0	1	0	0	0	0	0
rather far	0	0	0	0	0	1	0	0	0	0
very far	0	0	0	0	0	0	1	1	0	0
extremely far	0	0	0	0	0	0	0	0	1	1

Fuzzy 1.1	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
extremely near	1	1	.7	.2	0	0	0	0	0	0
very near	.2	.7	1	1	.7	.2	0	0	0	0
rather nearby	0	0	.2	.7	1	.7	.2	0	0	0
rather far	0	0	0	.2	.7	1	.7	.2	0	0
very far	0	0	0	0	.2	.7	1	1	.7	.2
extremely far	0	0	0	0	0	0	.2	.7	1	1

Table 7: Semantics to identify denotationally true core- and hedge-predicates (under *crisp* and *fuzzy* interpretation) in correct sentences being generated for fixed (unchanged) object locations (OL) and mobile (varying) system positions (SP).

											BEHIND											
	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	
	0	0	2	2	2	2	4	4	4	4		1	1	1	1	1	1	0	0	0	0	
	0	0	2	2	2	2	4	4	4	4		1	1	1	1	1	1	0	0	0	0	
	0	0	2	2	2	2	4	4	4	4		1	1	1	1	1	1	0	0	0	0	
	0	0	5	5	5	5	2	2	2	2		1	1	1	1	1	1	0	0	0	0	
	0	0	5	5	5	5	2	2	2	2		1	1	1	1	1	1	0	0	0	0	
	0	0	5	5	5	5	2	2	2	2		1	1	1	1	1	1	0	0	0	0	
R	0	0	4	4	4	4	2	2	2	2		1	1	1	1	1	1	0	0	0	0	L
I	0	0	4	4	4	4	2	2	2	2		1	1	1	1	1	1	0	0	0	0	E
G											▽											
H	0	0	1	1	1	1	1	1	1	1		6	6	3	3	3	3	0	0	0	0	F
T	0	0	1	1	1	1	1	1	1	1		6	6	3	3	3	3	0	0	0	0	T
	0	0	1	1	1	1	1	1	1	1		3	3	7	7	5	5	0	0	0	0	
	0	0	1	1	1	1	1	1	1	1		3	3	7	7	5	5	0	0	0	0	
	0	0	1	1	1	1	1	1	1	1		3	3	4	4	4	4	0	0	0	0	
	0	0	1	1	1	1	1	1	1	1		3	3	4	4	4	4	0	0	0	0	
	0	0	1	1	1	1	1	1	1	1		3	3	4	4	4	4	0	0	0	0	
	0	0	1	1	1	1	1	1	1	1		3	3	4	4	4	4	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	
											IN FRONT											

Table 8: $Endo1_{i,j}$ value distribution of sums of grid point marks according to (*crisp*ly interpreted) hedged core predicate adjacencies as found in the cluster dendrogram computed from the semantic space data of texts which describe SP-OL relations for a mobile system (▽) oriented south.

					NORTH						
	226	240	251	232	213	194	164	141	118	95	
	240	260	274	257	240	223	192	168	144	120	
	251	274	**295**	284	271	258	226	201	176	151	
W	237	262	289	285	277	269	238	216	194	172	*E*
E	223	250	280	280	276	272	242	223	204	185	*A*
S	209	238	271	275	275	275	246	230	214	198	*S*
T	191	222	258	269	276	283	258	243	228	213	*T*
	173	206	245	263	277	**291**	270	256	242	228	
	144	176	214	236	254	272	256	244	232	220	
	119	150	187	212	233	254	242	232	222	212	
					SOUTH						

Table 9: $Endo2_{m,n}$ showing regions of OL (object-location) likelihood computed for each grid point m, n by superimposing locality patterns from $Endo1_{i,j}$ values according to *Equ.* 18.

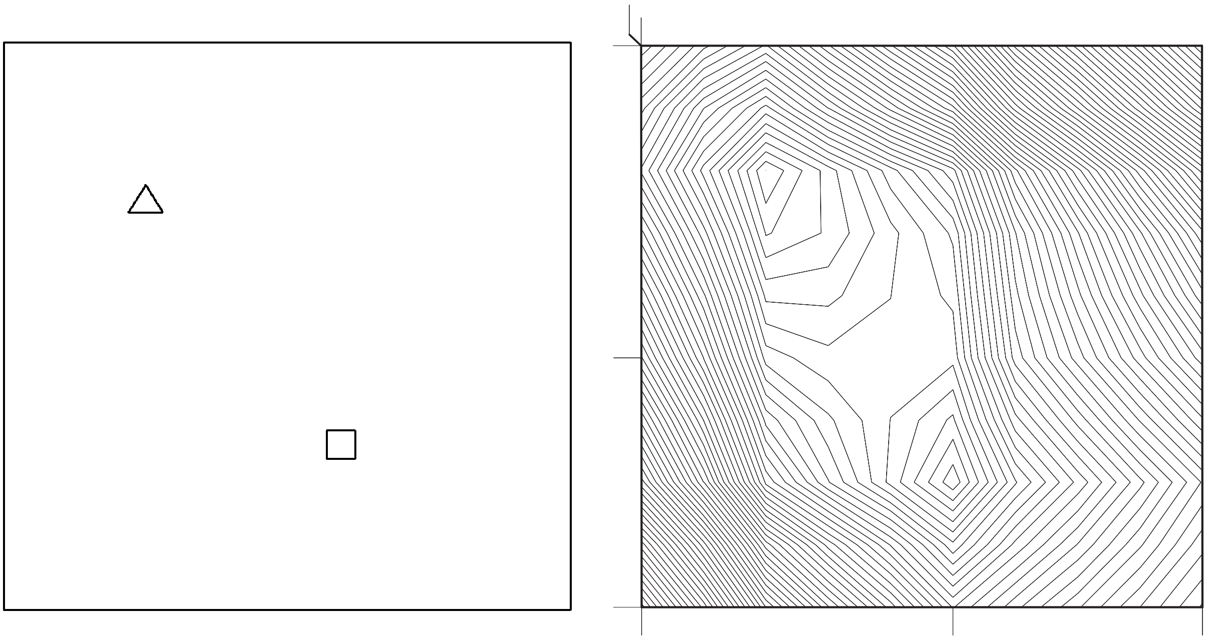

Figure 6: Reference plane (*left*) with location of objects (△ and □) propositionally described by texts in the training corpus **and** resulting 2-dim-image (*right*) of SCIP system's *endo*-view after processing the text corpus, showing regions of potential object locations (*iso-referentials*) as computed under crisp hedge interpretation.

central position in an intermediate $Endo1_{i,j}$ data structure (*Tab.* 8). From this intermediate representation the system's processing arrives at its own *internal* perception of the environment by

▷ third, computing the transformation according to (18) to yield the $Endo2_{m,n}$ data determining the system's *endo*-view of its environment which is an orientation independent structure (*Tab.* 9). It can be visualized in another format as

▷ fourth, a holistic representation comparable to the referential plane now structured by a pattern of polygons which connect regions of equivalent denotational likelihood—named *iso-referentials*—of possible object-locations in a two-dimensional format (*Fig.* 6 right part) or in a three-dimensional image (*Fig.* 8) according to the texts processed.

Transforming the $Endo1_{i,j}$ data matrix (*Tab.* 8) to become the $Endo2_{m,n}$ data matrix (*Tab.* 9) according to the equation

$$Endo2_{m,n} = \sum_{i=m}^{m+10} \sum_{j=n}^{n+10} Endo1_{i,j} \tag{18}$$

is a line- and column-wise summation of values which can be viewed as a replica of the system's stepwise movement along grid points in the reference plane which allowed to generate the SP-OL descriptions. Therefore, the matrix $Endo2_{m,n}$ (*Tab.* 9) contains the structural information for an external *observer's* image of the system's *endo*-view as computed globally from the corpus of texts which described SP-OL relations in a predicative and propositional way. The overall picture of (interpolated) points corresponding to degrees of even referential likelihood (*iso-referentials*) produces two object locations (OL) by way of two- and three-dimensional scattergrams (*Fig.* 6 right part, and *Fig.* 8 respectively) and denotes the potential objects clearly, however *fuzzy*.

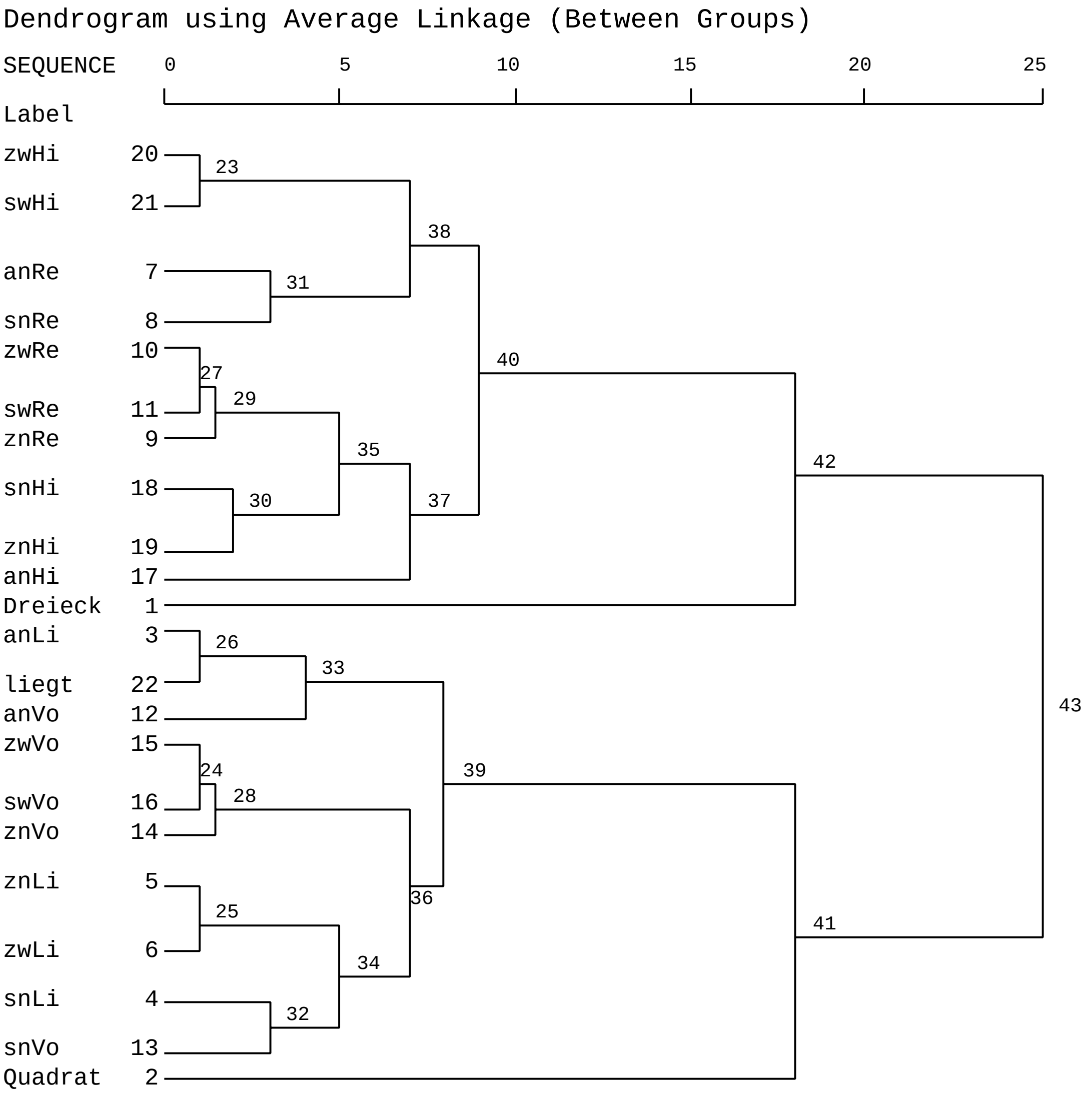

Figure 7: Dendrogram of internal SHS-structure of labels of hedged core predicate adjacencies as analyzed from textual object location descriptions relative to system positions oriented south (Labels denote: a = *extremely*, s = *very*, z = *rather*, w = *far*, n = *near*, Li = *on the left*, Re = *on the right*, Vo = *in front*, Hi = *behind*, Dreieck = *triangle*, Quadrat = *square*, liegt = *lies*).

The *fuzziness* of this image is quite remarkable in so far as it does not concern the object locations themselves but rather the referential space around them allowing for their differentiation. This sort of holistic and *indirect* way of specification—as opposed to the *direct* by stating two coordinate values to determine a location—is self-including and organized around the entities to be specified. It does not, therefore, need (or rely on) any categorial presuppositions of how points may be defined exterior to the self-organizing process whose emergent results structure space in a way to allow it to become (potentially) *referential*. It should be noted here, however, that the initial format of visualization chosen to be a two-dimensional plane spanned by orthogonal coordinates is not a situational necessity of the space concept but only the most conventionalized

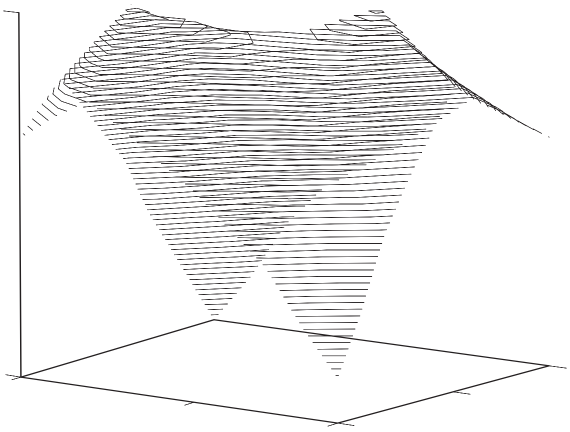

Figure 8: *3-dim*-profile according to Tab. 9 data of the SCIP system's *endo*-view of its *reality* showing highest potentials for object locations (OL) under *crisp* hedge interpretation, as computed from the training corpus of texts describing these locations relative to system positions (SP) in the reference plane.

frame for representing definite locations by abstracting from their situational embedding.

What can be concluded from what has been outlined so far? The strict separation of the computational *processes* from their *results* on the system's side now corresponds to the sharp distinction between the formal specification to control the propositional *generation* of descriptive language material and the *image* of the object locations (OL) relative to varying system positions (SP) of which this language material is a referentially true description. As the language material is in both cases the medium of representation for objects located in the reference plane at certain places, it serves well as the postulated *structural coupling* for testing a SCIP system's performance to collect and represent referential information from discourse. It is worthwhile noting here again, that the SCIPS's processing is neither based on, nor does it involve any knowledge of *syntax* or *semantics* on the system's side.

As soon as gradation (or *fuzziness*) is included as a consequence of a co- and contextual[36] situatedness—i.e. according to the SCIP system's basal assumption by way of textual language descriptions of object locations relative to system positions (*described situations*) and their actualization or *understanding* by the system concerned (*discourse situations*)—the representational frame is immediately extended by structural information that more conventional (symbolic) frames of (rule based) representations can only cope with by adding other dimensions ad hoc.

The non-propositional processing of a set (*corpus*) of sets (*texts*) of correct language expressions (*sentences*) of true meanings (*propositions*) describing object locations (fixed) relative to system positions (changing) resulted in a topology (dynamic) of labeled meaning points. Being in a vector space format (SHS), its intrinsic structure was made visible by three consecutive

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[36] The *cotextual* embeddedness of language entities is preserved in our definitions of *word, sentence, text* and *corpus* (*Tab.* 5) whereas the *contextuality* is determined by the structural SCIP system-environment coupling (*Fig.* 5) procedurally enacted by our model of language sign processing.

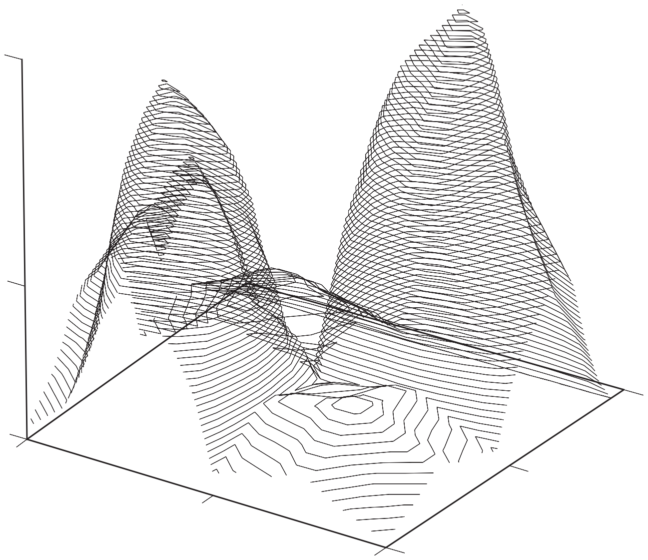

Figure 9: *3-dim*-image of the *SCIP* system's *endo*-view of regions showing highest potentials for object locations under $fuzzy_{1.1}$ hedge interpretation, as computed from the training corpus of texts describing these locations relative to system positions in the reference plane.

stages of representations. These visualizations were based on the $crisp_{1.0}$ interpretations of the hedges. Using instead the $fuzzy_{1.1}$ definitions (*Tab.* 7) to interpret the adjacencies of hedged core predicate labels as analyzed in the cluster dendrogram (*Fig.* 7) has produced comparable images of emerging structuredness that was visualized accordingly in the form of three-dimensional *iso-referentials* (*Fig.* 9).

What is surprising though, is the fact that these *exo*-representations of the system's *endo*-view appear to provide a more immediate image of the referential space structure under $fuzzy_{1.1}$ than under $crisp_{1.0}$ interpretations of hedges. Derivable from the *fuzzy* semantic data is a more clearly structured image without the transform of intermediate data structures which are needed according to (18) in the case of *crisp* semantic interpretation of the data. A still very tentative explanation may be offered by assuming that the *fuzzy* interpretation of hedged core predicate adjacencies on this (*representational*) level appears to enhance the effect which the changing positions of the system do produce on the *situational* level. Described by differing language expressions to denote varying but definite SP-OL relations (of system positions and object locations) under *crisp* interpretation of hedges, these variations seem to be mimetically enlarged in the $fuzzy_{1.1}$ definitions of hedged predicates. As the SCIP system was conceived as a mobile one, restricted by the defining conditions and properties (*Tab.* 3), its changing positions were constitutive for the controlled generation of (language) descriptions of (very restricted) referential situations. Therefore, it might not be too startling to find the overall structure emerging from *non-propositional* processing of pragmatically homogeneous *propositional* descriptions of situations no longer in want of a computational transformation. It may be concluded that its results can apparently be compensated or rather anticipated by the more semiotic substitute or rather principle intrinsic to natural language structuring, i.e. by *fuzzy* instead of *crisp* definitions and interpretations of hedges.

6 Semiotic Computing with Words

The problem of visualizing results of computational procedures developed to model and realize semiotic processes whose numerical representations—by definition—do not have an immediate interpretation, is apparent. Confining to the level of *semantic* word meaning constitution, various techniques have been developed and applied in the past [45] [46] [47] [48] [49] to analyze, scrutinize, and visualize emergent structures in distributed representations of vectors of labeled meaning components as determined by functions of differences of usage regularities computed from natural language discourse corpora. These approaches were able to demonstrate the definite non-contingency of *meaning points* $z \in S$ in *semantic hyperspace* (SHS). Hence, its structure may serve as base for a number of procedures to operate on. Their algorithmic implementations as well as the results produced by these algorithms allow to demonstrate the *semiotic* quality of procedural models of non-symbolic information processing, i.e. illustrating their meaning constitutional performance and their ability to represent such meanings in a usable, easily interpreted format of tree-like graphs whose hierarchically structured connotative dependencies (CDS) [41], associative dependencies (ADS) [44], and dispositional dependencies (DDS) [56] converge in a particular type of semantic relatedness of co- and contextually sensitive, focal perspectivity[37].

6.1 Semantic Dispositional Dependencies

Following the semiotic understanding of meaning more as a constitutional process rather than an entity of invariable constancy or static representation, the presented SHS may be considered part of a word meaning/world knowledge representation system which separates the format of basic (stereotyped) meaning components (*meaning points*) from their latent (dependency) relational organization as meaning potential (*semantic dispositions*). Whereas the former is a static, topologically organized multi-dimensional memory structure, the latter can be characterized as a dynamic and flexible structuring process which (re)organizes and thereby transforms the basic relatedness of the elements it operates on.

This is achieved by a recursively defined procedure that produces a hierarchical ordering of the SHS's meaning points which can be represented as a tree structure organized under a given aspect (root node) according to and in dependence of its neighbors' co- and contextual relevancy. Taking up ideas from cognitive theories of *semantic memory*, *priming*, and *spreading activation* [25], the DDS-algorithm was devised to operate on the semantic space data and to generate a *dispositional dependency structure* (DDS) in the format of an n-ary tree. Given one meaning point's position, the algorithm will

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[37] These tree structures differ according to their underlying procedures and algorithms which were developed to operationalize different aspects of (*connotative*, *associative* and *dispositional*) dependencies. Their potentiality is visualized in possible meaning relations which these algorithms assemble and organize under the root node's focus in a hierarchy of *dependency graphs* which are represented in a perspectively *structured* form.

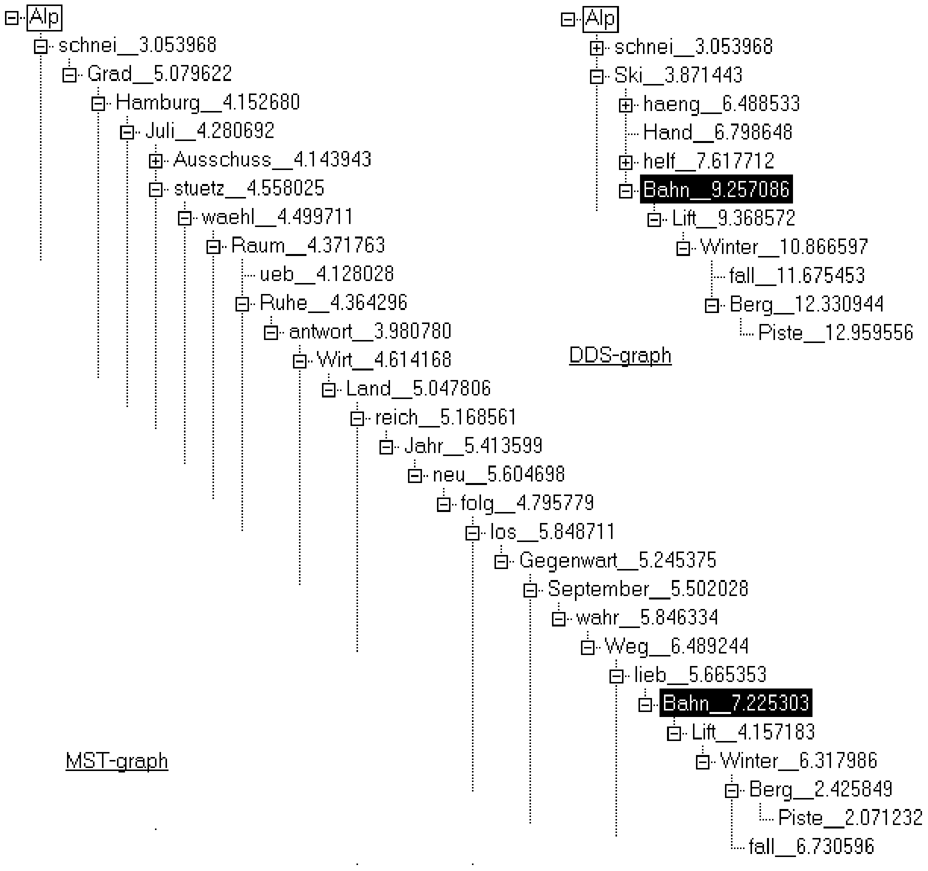

Figure 10: Fragment of MST-graph of `Alpen`*Alps* (root) as generated from the *semantic space* data ($V = 345, H_i \geq 10$) of a German newspaper sample (DIE WELT, 1964 Berlin edition), contrasted with a fragment of the DDS-tree (upper right)as generated for the same root node `Alpen/` and from the same SHS-data.

1. take that meaning point's label as a start,
2. stack labels of all its neighboring points by their decreasing distances,
3. instantiate DDS-tree with head or root node being the starting point's label. The process continues to
4. take label from top of stack as next daughter node,
   4.1 list labels of all its neighbors,
   4.2 intersect list with nodes in tree,
   4.3 determine from intersection the least distant one as mother node in tree,

5. link daughter to identified mother node, and
6. repeat 4. either
   6.1 until 2. is empty, or
   6.2 other stop condition (pre-set number of nodes to be processed, maximum distance from starting point, etc.) is reached
7. to end.

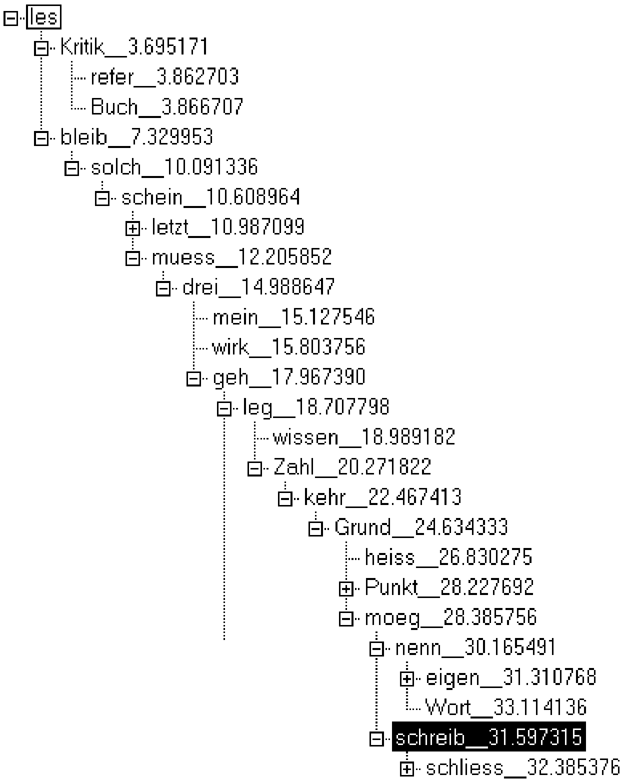

Figure 11: *Dependency path* of `lesen`/*to read* $\Longrightarrow$ `schreiben`/*to write* as traced in DDS-tree of `les`.

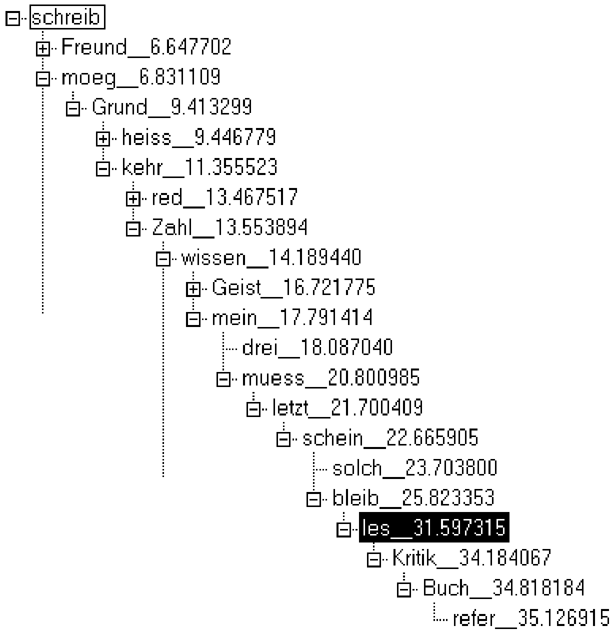

Figure 12: *Dependency path* of `schreiben`/*to write* $\Longrightarrow$ `lesen`/*to read* as traced in DDS-tree of `schreib`.

Apparently, although the DDS-algorithm can simply be characterized as a greedy, encapsulated *minimal spanning tree* (MST) generating procedure [34] which consumes all meaning points $z_n \in \langle S, \zeta \rangle$, this encapsulation serves a meaning constituting purpose catching *semiotic* properties of emergence and representation of structure which are tied to its contextuality. Where the MST is searching for shortest possible connection between points qualifying for tree node relatedness, the DDS is looking for highest *meaning similarities*, i.e. for shortest possible distance relations between points which are determined as *semiotically* derived representations of meaning components as computed from textual structures (discourse). It is this property that allows the algorithm's search space to be reduced and *semantically* constrained on the starting point's or root node's topological environment (capsule) which renders the tree perspective, i.e. *aspect*-dependent and structurally *context sensitive*.

The tree structured graphs[38] may serve as a visualization of the discriminating relatedness that any labeled meaning point $z_i \in \langle S, \zeta \rangle$ chosen as root node will produce according to his and other points' adjacencies in the SHS data structure (*Fig.* 10). Their primal topological relatedness in SHS—being determined by and reconstructed operationally as a function of the differences of usage regularities of word distributions in the texts analyzed—will thus allow for a directed, non-

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[38] The figures present fragments of trees of a SHS structure which was computed from a sample of texts from the German daily newspaper (Die Welt, 1964, Berlin edition); $\oplus$ marked nodes hide conflated sub-trees not expanded here; the numerical values stated are direct ζ-distances from the root node.

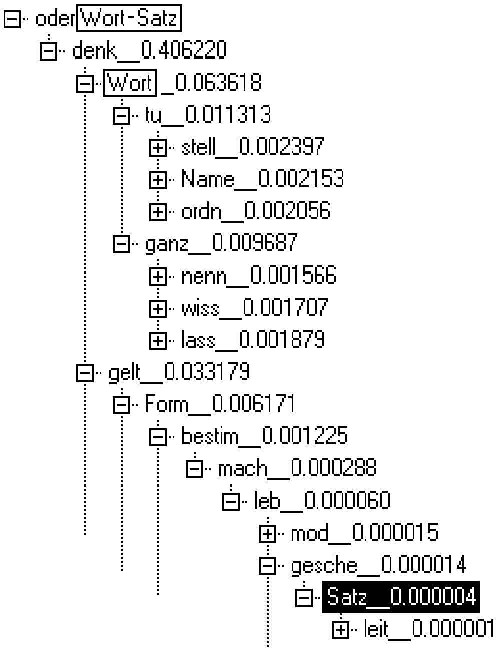

Figure 13: Fragment of DDS of `Wort`/*word* ∨ `Satz`/*sentence* as generated from OR-adjunction (max.) of meaning points in *semantic space*.

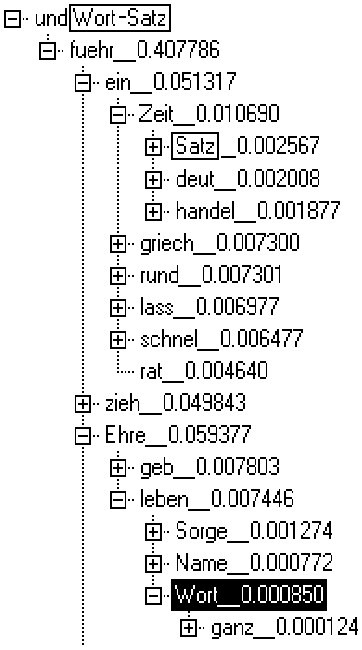

Figure 14: Fragment of DDS of `Wort`/*word* ∧ `Satz`/*sentence* as generated from AND-conjunction (min.) of meaning points in *semantic space*.

symmetric relation (*dependency*) being procedurally declared and induced on the SHS structure of *meaning points* z_i, depending on the start area, i.e. the meaning point's position chosen as the tree's root node. Such topology based *dependencies* guarantee that from all related meaning points the most relevant will be related also in the generated tree structure. The *dependencies* which may be weighted, will vary in degree by the tree level they occur in, and in context according to the semantic *aspect* (or starting point chosen as root node) under which it is algorithmically generated. This type of tree has been named *dispositional dependency structure* (DDS) because it may be considered a dynamic structure whose generation and assembly of possible meaning points will vary according to the modifications of the SHS structure it is derived from.

6.2 Semiotically Generalized Constraints

The DDSs can be considered an alternative procedural format of *fuzzy information granulation* which extends the rule-based frame as introduced by the concept of *generalized constraint* [70] and exemplified in [71] as *unconditional constraints*.

According to ZADEH (1997), a generalized constraint on values of X is expressed as X *isr* R, where X is a variable which takes values in a universe of discourse U, *isr* is a variable copula with r being a discrete variable whose values define the way in which R constrains X, and R is the constraining relation. For r the different values defined are *equality, possibility, verity, probability, probability value, random set,* and *fuzzy graph* and the related (definitional, operational, procedural, computational) interpretations are given. It is important to observe that r relates to R in a predicative sense specifying the interpretation of R (generally being a distribution of grades of membership) as *possibilities, truth values, probabilities* or composites thereof. The distinction of functional types of r to control the interpretation of R is necessary for rule-based mechanisms of inferential processing but may become obsolete for algorithmic procedures in CS operating on well-defined value distributions.

> In addition to the types of constraints defined above there are many others that are more specialized and less common. A question that arises is: What purpose is served by having a large variety of constraints to choose from? A basic reason is that, in general setting, information may be viewed as a constraint on a variable. (ZADEH 1997, p. 117)

However, as has been shown above, constraints can not only be induced by predicative expressions of truth-functional propositions but may also be induced by word meanings, provided these are modeled by procedurally determined weighted dependency relations in SHS data derived from natural language discourse analyzed in a *fuzzy linguistic* manner. Taking the concept of a generalized constraint to hold likewise for the levels of sentence meanings (proposition) as well as for word meanings (DDS), then the TFIG notational format introduced may be translated to $X \simeq \{z_n\}$ where X is a variable which takes values $z_i \in \langle S \rangle$ with $S \subseteq U$. A semiotically generalized constraint on values of X is expressed by $X\ dds_i\ S$ where DDS_i relates z_i to S in a specifying way by restricting SHS procedurally in generating the DDS-graph *tree structure*) from meaning point z_i as its root, and z_n as its discrete variables whose values define different sub-graphs (*dependency paths*) which constrain S in a perspective way.

It should be noted here that the notion of *dependency path* is a structural representation of a dynamic concept of *granular word meaning* which induces a reflexive, partly symmetric, and weakly transitive relation between relevant meaning components. It allows for the procedural definition and computational enactment of *semantic* inferencing on the *word* level, very much like the *rule-based* models of inferencing in granular *fuzzy information* processing based on *fuzzy rules*, or the *syntagmatically* defined propositional formats of symbolic processing in (cognitive linguistic) sentence semantics based on *crisp* logic calculi.

Thus, a DDS tree can be said to (re)present meaning points—top down—as *granular* components whose dependency related *hierarchy* determines its—bottom up—*organization* by way of a structured potential for choice which is accessible by—and made visible through—procedural restrictions on the SHS $\langle S, \zeta \rangle$. Their actualized access then will be *causative* for the constitution of the meaning associated with (or rather enacted by) the expression of the root node's z_i language label $x_i \in V$ or vocabulary item employed in discourse.

6.3 Representational Properties

There are a number of consequences to be derived from DDS properties of which the following seem interesting enough to be listed and shortly commented on:

- ▷ In order to illustrate the *contextual sensitivity* which distinguishes the DDS-algorithm from e.g. *minimal spanning trees* (MST) [34], the latter (*Fig.* 10) has been generated from the same data with the same starting node. Note, that the sub-trees of `Bahn` (*track, course, trail*) identical in both, the MST- and the DDS-tree, are found on extremely different levels (MST 23 comparing to DDS 3)[39].

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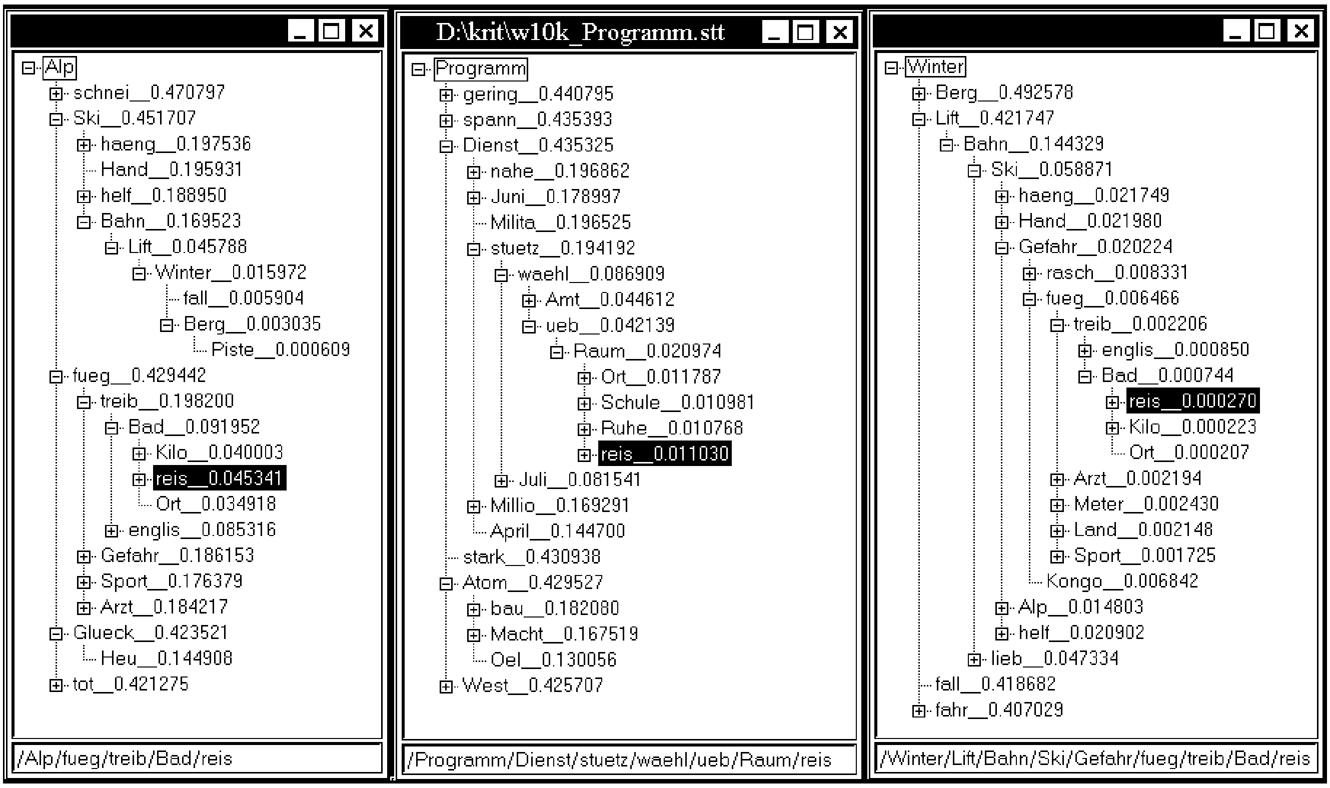
[39] The numerical MST values given are direct ζ-distances between nodes (mother-daughter pairs).



```
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    ⊟ Ski__0.451707
        ⊞ haeng__0.197536
          Hand__0.195931
        ⊞ helf__0.188950
        ⊟ Bahn__0.169523
            ⊟ Lift__0.045788
                ⊟ Winter__0.015972
                      fall__0.005904
                    ⊟ Berg__0.003035
                          Piste__0.000609
    ⊟ fueg__0.429442
        ⊟ treib__0.198200
            ⊟ Bad__0.091952
                ⊞ Kilo__0.040003
                ⊞ reis__0.045341
                  Ort__0.034918
            ⊞ englis__0.085316
        ⊞ Gefahr__0.186153
        ⊞ Sport__0.176379
        ⊞ Arzt__0.184217
    ⊟ Glueck__0.423521
          Heu__0.144908
    ⊞ tot__0.421275
/Alp/fueg/treib/Bad/reis
```

```
⊟ Programm
    ⊞ gering__0.440795
    ⊞ spann__0.435393
    ⊟ Dienst__0.435325
        ⊞ nahe__0.196862
        ⊞ Juni__0.178997
          Milita__0.196525
        ⊟ stuetz__0.194192
            ⊟ waehl__0.086909
                ⊞ Amt__0.044612
                ⊟ ueb__0.042139
                    ⊟ Raum__0.020974
                        ⊞ Ort__0.011787
                        ⊞ Schule__0.010981
                        ⊞ Ruhe__0.010768
                        ⊞ reis__0.011030
            ⊞ Juli__0.081541
        ⊞ Millio__0.169291
          April__0.144700
      stark__0.430938
    ⊟ Atom__0.429527
        ⊞ bau__0.182080
        ⊞ Macht__0.167519
          Oel__0.130056
    ⊞ West__0.425707
/Programm/Dienst/stuetz/waehl/ueb/Raum/reis
```

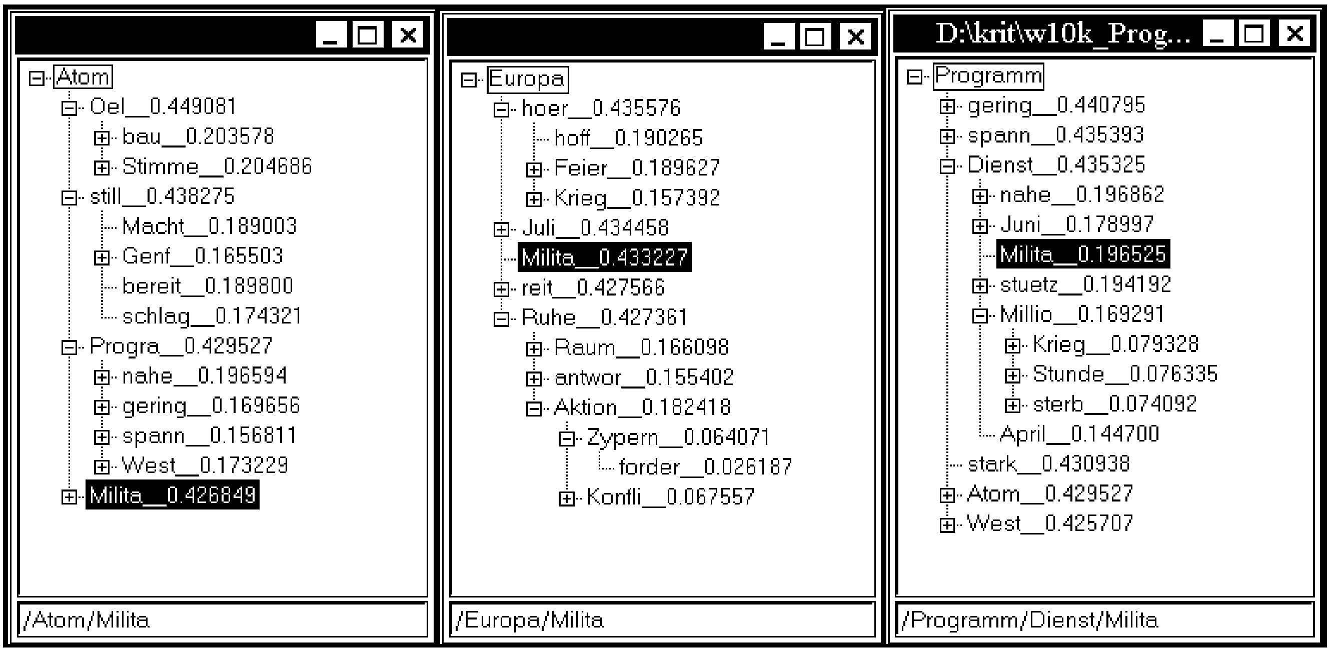
```
⊟ Winter
    ⊞ Berg__0.492578
    ⊟ Lift__0.421747
        ⊟ Bahn__0.144329
            ⊟ Ski__0.058871
                ⊞ haeng__0.021749
                ⊞ Hand__0.021980
                ⊟ Gefahr__0.020224
                    ⊞ rasch__0.008331
                    ⊟ fueg__0.006466
                        ⊟ treib__0.002206
                            ⊞ englis__0.000850
                            ⊟ Bad__0.000744
                                ⊞ reis__0.000270
                                ⊞ Kilo__0.000223
                                  Ort__0.000207
                        ⊞ Arzt__0.002194
                        ⊞ Meter__0.002430
                        ⊞ Land__0.002148
                        ⊞ Sport__0.001725
                      Kongo__0.006842
                ⊞ Alp__0.014803
                ⊞ helf__0.020902
            ⊞ lieb__0.047334
      fall__0.418682
    ⊞ fahr__0.407029
/Winter/Lift/Bahn/Ski/Gefahr/fueg/treib/Bad/reis
```

Figure 15: DDS-based *semantic inference* (on criteriality values) from `Alpen/`*Alps*, `Programm/`*program*, and `Winter/`*winter* (premises) to `reis/`*travel* (conclusion) as computed from the semantic space data.

- ▷ The procedural (semiotic) approach replaces the storage of fixed and ready set relations of (semantic) networks in AI by source- or aspect-oriented induction of relations among meaning points by means of the DDS procedure;
- ▷ DDSs' dependencies may be identified with an algorithmically induced *relevance* relation which is reflexive, non-symmetric, and (weakly) transitive as illustrated by the *dependency paths*' listings of node transitions `les/`*to read* $\Longrightarrow$ `schreib/`*to write* and its (partial) inverse `schreib` $\Longrightarrow$ `les` (Figs. 11 and 12);
- ▷ The relevance relation gives rise to the notion of *criteriality* which allows to estimate to what degree a meaning compound (daughter node) contributes to the *meaning potential* a root node's DDS is to represent. It will render the DDS a weighted tree and may numerically be specified as a function of any node's level and ζ-distance by

  $$Cr_i(d)_{\kappa+1} = Cr_i(m)_\kappa \cdot e^{-\frac{\zeta(d,i)}{\lambda+\zeta(d,m)}} \tag{19}$$

  with i, m, d for *root*, *mother*, and *daughter* nodes respectively, and the counters κ for (left to right) nodes, and λ for (top down) levels in the tree;
- ▷ As the criteriality values are decreasing monotonously from 1.0 (root) they may be interpreted as membership values which reflect the relevance related, *softly* structured collection of components (nodes) in the DDS as a *fuzzy meaning potential*. Applying the set theoretical extensions for logical operators (*and, or, non,* etc.) opens new possibilities to generate composite meaning points (`Wort/`*word* $\vee$ `Satz/`*sentence*) in *Fig.* 13) without assuming a



```
⊟ Atom
  ⊟ Oel__0.449081
    ⊞ bau__0.203578
    ⊞ Stimme__0.204686
  ⊟ still__0.438275
      Macht__0.189003
    ⊞ Genf__0.165503
      bereit__0.189800
      schlag__0.174321
  ⊟ Progra__0.429527
    ⊞ nahe__0.196594
    ⊞ gering__0.169656
    ⊞ spann__0.156811
    ⊞ West__0.173229
  ⊞ Milita__0.426849
/Atom/Milita
```

```
⊟ Europa
  ⊟ hoer__0.435576
      hoff__0.190265
    ⊞ Feier__0.189627
    ⊞ Krieg__0.157392
  ⊞ Juli__0.434458
    Milita__0.433227
  ⊞ reit__0.427566
  ⊟ Ruhe__0.427361
    ⊞ Raum__0.166098
    ⊞ antwor__0.155402
    ⊟ Aktion__0.182418
      ⊟ Zypern__0.064071
          forder__0.026187
      ⊞ Konfli__0.067557
/Europa/Milita
```

```
⊟ Programm
  ⊞ gering__0.440795
  ⊞ spann__0.435393
  ⊟ Dienst__0.435325
    ⊞ nahe__0.196862
    ⊞ Juni__0.178997
      Milita__0.196525
    ⊞ stuetz__0.194192
    ⊟ Millio__0.169291
      ⊞ Krieg__0.079328
      ⊞ Stunde__0.076335
      ⊞ sterb__0.074092
      April__0.144700
    stark__0.430938
  ⊞ Atom__0.429527
  ⊞ West__0.425707
/Programm/Dienst/Milita
```

Figure 16: DDS-based *semantic inference* (on criteriality values) from `Atom/`*atom*, `Europa/`*Europe* , and `Programm/`*program* (premises) to `Militär`*military* (conclusion) as computed from the same semantic space data.

propositional structure and to get these composites' structural *meanings* determined by their DDSs as computed from the SHS data;

▷ The experiments run for *semantic inferencing* (SI) based upon DDS have turned out to be very promising. SI appears to be feasible without the need of having to state the premises in a predicative or propositional form prior to the concluding process. The DDS algorithm lends itself easily to the modeling of *analogical* reasoning processes by parallel a processing of DDS trees.

As illustrated in *Fig.* 15, the semantic inference process will start from two (or more) root nodes as semantic *premises* (here the three: `Alpen/`*Alps*, `Programm/`*program* and `Winter/`*winter*), it will then initiate the two (or more) DDS processes concerned each of which—in selecting its daughter nodes—will tag the respective meaning points in the semantic space. Stop condition for this process—which proceeds (*least distance* or *highest criteriality*) breadth first through the respective DDSs—is defined to be the first meaning point found to be tagged already by one (and all) other processes active. This point (here: `reis/`*travel*) will be considered the (first) candidate inferred or concluded from the premises (with the option to extend the number of candidates under different stop conditions). The *dependencies* activated (bottom line of *Fig.* 15) are three paths: 1st: *Alps* → *join* → *drive/propel* → *Spa*→ *travel*, 2nd: *program* → *service* → *support* → *choose* → *exercise* → *space/locality* → *travel*, and 3rd: *winter*→ *lift* → *course/track* → *ski*→ *danger* → *join* → *drive/propel* → *Spa*→ *travel*. They translate to the premises' *inference paths* resulting in the concluded meaning (`reis/`*travel*) whose connotative embedding is provided by the sub-trees shown according to its semantic relatedness mediated by the text material analyzed.

The *semantic inference* (SI) procedure may also give some hints how to exploit central aspects of *efficient* word usages which result in what is linguistically perceived as *homony-*

mous/polysemous meanings of lexical items when isolated from their cotexts. As connotativity of words in discourse is the functional core of structural meaning, opaque *compounds* common in German can be resolved on the grounds of DDS graphs used in semantic inferencing. This can well be illustrated by differences of connotations that words not only acquire due to other words they occur with in strings of texts, but which also indicate their new semantic values which therefore may serve as a structural means of representation. Depending on other lexical items in their cotextual environments (particularly obvious via compounding like e.g. in *Alpenprogramm, Atomprogramm, Europaprogramm* or *Winterprogramm*), their meanings can well be determined—instead of being defined propositionally—by their granular organization as represented by DDS-graphs and their inferential processing.

The two items `Atom/`*atom* and `Europa/`*Europe* have been chosen here as alternative premises for the *semantic inference* (SI) procedure with *program*, contrasting *Alps* and *winter* in *Fig.* 15 above. This resulted in semantic dependencies as shown in *Fig.* 16, depicting and conveying a notion of `Militärprogramm/`*military program* according to the dependencies listed (*program/ service/ military*) rather different from `Reiseprogramm/`*travel plan* with its divergent dependencies (*program/ service/ support/ chose/ exercise/ locality/ travel*) generated before in *Fig.* 15.

7 Conclusion

Devising representational structures which result from semiotic processing of natural language discourse as modeled by *semiotic cognitive information processing* (SCIP) systems is to explore *syntagmatic* and *paradigmatic* constraints on different levels of item combinability in *pragmatically homogeneous* texts. Although tentative still, hopefully SCIP systems do contribute to a deeper understanding of how entities and structures are constituted that may indeed be called *semiotic*, i.e. do not only have an objective (material) extension in space-time, but can beyond that be understood as having interpretable (semantic) meaning.

For natural as well as artificial SCIP systems, in order to be able to identify signs and to interpret them as representational of what they stand for, these systems need to have not only an adaptive structure which is able to perform accordingly, but which is self-organizing also in a semiotic, i.e. meaning constituting sense of performance. As has often been and still is experienced, most of the automatic symbol processing devices available so far fail to serve this purposes and do not perform too well when applied to deal with problems of natural language understanding which we find difficult even to describe, analyze, or define at present in a principled way. Procedural modeling and computational realization of living organisms' cognitive behaviors would appear to offer some chances for moderate progress in that respect.

From a cognitive science point-of-view, mind/brain activity is essentially computational *information processing* which can be modeled accordingly, i.e. as rule-based symbol processing mechanisms. From a systems theoretic perspective, the fundamentals of cognition are viewed as a means of *structuring* an environment as perceived by (artificial or natural) information processing systems. The semiotic grounding of such structuring (*process*) adds the means of *representing* this structure (*result*) in some—not necessarily symbolic—format in order to preserve or to communicate some of it to other systems. This combination of structuring process and structured result as mediated by representations (*memory*) gave rise to the theory of *Semiotic Cognitive Information Processing Systems* whose testbed is natural language understanding. It might add coverage of considerable complexities of sign based cognitive processes. Apparently, *soft computing* with words has embarked in tackling central issues stemming from these complexities, by relaxing the widely deterministic machinery of rule-based symbolic models employed for information processing by machine so far.

The dynamics of *semiotic* knowledge structures and the processes operating on them essentially consist in their recursively applied mappings of multilevel representations resulting in a multiresolutional granularity of fuzzy word meanings which emerge from and are modified by such text processing. Test results from experimental settings (in semantically different discourse environments) illustrate the *SCIP* system's granular language understanding and meaning acquisition capacity without any initial explicit morphological, lexical, syntactic and semantic knowledge.

Due to the centrality of *semiosis* and its pivotal role in language understanding, SCIP systems are designed to emulate the process of sign and/or meaning constitution by machine without (necessarily) replicating the procedural components and/or representational means as employed and enacted by humans. Following the systems theoretical approach, the modeling basically places an information processing *system* into an *environment* whose *structural coupling*—as realized by the mediating processes and their representational results—allows for the distinction of both. When we think of natural language structures and their actualization in discourse understanding in these terms of representation and process, the generality of the conception lends itself easily to accommodate hierarchically structured restrictions on modes of processing (*granulation, organization, causation*) which determines categorial differences of entities to be dealt with. Thus, *data* processing according to predefined rules is distinguished from *information* processing under given and pre-established interpretations; information processing is called *cognitive* whenever these interpretations have to be derived from sets of principled structures according to certain mechanisms the processing system is endowed with as its (internal or external) knowledge base. And cognitive information processing will become *semiotic* to the extent in which this knowledge is acquired, structured, and/or modified according to the system's own processing capabilities and intrinsic structuring principles. They do allow not only for the (internal) representation of results of such processing, but also for their (externalized) representation (sign structures) giving access to them by way of mediation. Mediation can be defined as the capacity of sign structures to activate the associated functions in SCIP systems properly attuned. This is roughly what *understanding natural language sign structures* translates to in a SCIP system-environment situation.

Favoring such a *semiotic* (re)orientation has its practical import on possible application. As information proves to be essential to any decision process and vital to optimal ones, the availability, support, and affordance of relevant data, information, and understanding becomes a prerequisite to correct decisions which—ideally—are to be found in order to act, plan, or decide accordingly. For these processes, some components may be identified whose semiotic, i.e. sign and meaning constitutive relatedness—by and large—has been overlooked so far. It can be envisaged, however, that it may be specified operationally and incorporated systematically in order to replenish and improve the explicative understanding of what *language understanding*—beyond the anatomy of planned decisions of/for action and its modes of (possible, if not even necessary) realization processes—is going to mean.

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