Semiotic Cognitive Information Processing: Learning to Understand Discourse.

A systemic model of meaning constitution.

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1 Introduction

Human beings appear to be very particular information processing systems whose outstanding plasticity and capability to cope with changing environmental conditions (*adaptation*) is essentially tied to their use of natural languages in communication to acquire knowledge (*learning*). Their knowledge based processing of *information* makes them *cognitive*, and their sign and symbol generation, manipulation, and understanding capabilities render them *semiotic*. *Semiotic cognitive information processing* (SCIP) is inspired by information systems theory according to which living systems process and structure environmental data according to their own structuredness. When these processes are modeled as operating on structures whose representational status is not so much a presupposition to but rather a result from such processing, then the resulting models – being able to simultaneously instanciate, create and/or modify these structures – may attain a quality of sign and symbol *understanding* which may computationally be realized. This quality will in the sequel be studied and identified as a particular form of knowledge acquisition or *learning* whose results can be visualized as incremental dynamics of structure formation. Its formal delineation, operational specification, and algorithmic implementation allows for experimental testing of the SCIP system's capability for *meaning constitution* from natural language texts without prior morphological, lexical, syntactic and/or semantic knowledge.

In response to deficits encountered likewise in computational linguistics (CL), artificial intelligence research (AI) and cognitive psychology (CP) whose theoretical and applicational problems in understanding natural language information processing by men and machine are becoming exceedingly pressing, the last two decades saw a certain renaissance in *semiotics*. The new interest in the cognitive foundations of sign organization and manipulation processes was spurred even further by artificial life research (AL) and the quest for a principled theory of understanding symbols and languages, models and (re)presentations, simulations and realizations. Such a theory is expected to supply some grounding also for knowledge acquisition as a conception of *learning* whose formal derivation, procedural instanciation, and testable results provide some symbol and language independent evidence of what can be (said to be) understood.

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Following these introductory remarks (1.) will be a short characterization of the *cognitive view* (2.) to language understanding and the lay-out of a *system theoretical frame* for cognitive processing (3.), before on the grounds of both the *computational semiotics* perspective (4.) of memory, knowledge, and understanding is developed. Introducing the functional relevancy of *language structures* (5.) and their granular decomposition will set the stage for an *empirical reconstruction* (6.) and the *experimental testing* (7.) of the (tentative) design and (implemented) modeling of a semiotic cognitive information processing (SCIP) system whose testable language understanding performance is considered an instanciation of enactive *learning* as summarized in the *conclusion* (8.).

2 The Cognitive Science View

Common ground and a widely accepted frame for the investigation of phenomena of cognition, knowledge, and understanding has been – and for some still is – the founding duality in the rationalistic tradition of thought. As exemplified by the Cartesian notion of some objective reality (*res extensa*/matter) and the subjective conception of it (*res cogitans*/mind), this distinction is tantamount to the division of reality in how it may either subjectively be experienced based on sense impressions (*endo-view*) and/or objectively be studied in a scientific way[1] (*exo-view*) as based upon observable representations. It is these representations which seem to allow for inter-subjective mediation of what eventually may end up to be called (objective) reality to the extent to which this mediating process is successful in being reproducible, repeatable, and made testable by observing rule governed operations of identification, measurement, and calculation.

2.1 PSSH and Cognitive Modeling

The principles of empirical research derived from this Cartesian cut determine the problem space which also allows for the location of cognition as being dealt with in this paper[2]. Its shift of focus, however, away from objective reality and subjective experience on to the processes that do not only mediate between both but might be considered also their precondition, induces a very specific, i.e. semiotic perspective to cognition. Concentrating on the employment of (natural) language signs and the

[1] "Science is based on observation, hence on the use of the senses. The problem is to eliminate the subjective features and to maintain only *statements* which can be confirmed by several individuals in an objective way [...] Science aims at a closer *relation* between *word* and *fact*. Its methods consists in finding correlations of one kind of subjective sense impressions with other kinds, using the one as indicators for the other, and in this way establishes what is called a fact of observation." [6, p.33, *my italics*]

[2] "In particular, it is based on an experimental approach in which progress is made by performing experiments that can directly judge between competing scientific hypothesis about the nature of cognitive mechanisms. In most experiments situations are created in which the variety of actions is strictly controlled and only a very limited aspect of situation is considered relevant to the pattern of recurrence.[...] The assumption underlying this empirical research is that general laws can be found in these restricted cases that will apply (albeit in a more complex way) to a much broader spectrum of cognitive activity." [66, pp. 24]

understanding of meanings they convey, this shift will suggest the revision of some seemingly well established views in the course of which the above duality shall be overcome, although not given up in its entirety.

The semiotic perspective is not to be confused with Newell's *physical symbol system hypothesis*[3] (PSSH) [27] which gave rise to the computer metaphor [25] that rests on the suggestive resemblance between mind and computer and served as a guideline in early cognitive sciences [17]. It tends to determine even recent models of cognitive systems and natural language processing [38] in hiding, rather than addressing the central issues by presupposing an immediate understanding of what in fact stands in need of mediated explanation[4]. Hence, some of the computer metaphor's seminal conceptual distinctions and their terminological derivatives will in the sequel be employed where necessary to bring home our issue in revising them.

A case in point is the notion of *mental models* conceived as internal images or representations of those (structures of) entities external to the cognitive system. They are said to correspond to that very segment (or layer of the organization) of the real world the system has to adapt to, or has to control in order to survive. In presupposing the duality of the mind/matter division to be fundamental, most cognitive models and their explication of natural language understanding (as well as nearly all realistic theories and models of referential semantics) readily identify – in accord with PSSH – mental images (or internal representations) of the external world with what natural language expressions may convey when understood. Consequently, cognitive processing and understanding of natural language expressions in particular is hypothesized to be modeled as a mapping of percepts and/or language structures onto mental images or internal representations. As their relations to the external world are pre-established by definition, the mental images' (semantic) interpretability is unquestionable and seems to justify them being named *meanings*.

Accordingly, *understanding* meanings appears to be a form of cognitive processing conceived as an activity that (somehow) relates certain (structures of) entities (e.g. objects, signs) observed in reality, to concepts and conceptual structures (e.g. mental images, internal representations) in the mind that are not directly observable. This observational deficit apparently was not considered too serious an impediment as it could easily be compensated by the core assumption the PSSH had formulated,

[3] According to Simon: "A physical symbol system holds a set of entities, called symbols. These are physical patterns (e.g. chalk marks on a blackboard) that can occur as components of symbol structures (sometimes called 'expressions'). [...] a symbol system also possesses a number of simple processes that operate upon symbol structures – processes that create, modify, copy, and destroy symbols. A physical symbol system is a machine that, as it moves through time, produces an evolving collection of symbol structures. Symbol structures can, and commonly do, serve as internal representations (e.g. 'mental images') of the environments to which the symbol system is seeking to adapt." [63, p.27]

[4] As emphasized nearly three decades ago by Pattee who identified the dependence of biological systems on *physical constraints* together with their ability of internal self-interpretation as being constitutive for *symbol structures*: "And this interpretation is not a property of the single molecule, which is only a symbol vehicle, but a consequence of a coherent set of constraints with which they interact [... raising the question of representation so] that the most fundamental concept of a constraint in physics depends on an *alternative description*, and that the apparent simplicity of constraints is in fact a property of the language in which it is described." [28, pp. 248]

namely, that internal images and their conceptual relations can be represented as (or even have the structure of) propositions. This made the whole framework available to the cognitive study of conceptual structures which logics and linguistics had so far developed and successfully employed as analytical and representational tools for language structures (up to the sentence boundary), with the additional advantage that the formats of representational results from cognitive analyses of mental structures (mind) and those from linguistic[5] analyses of language structures (meaning) would be the same. Although an identification on apparently hypothetical grounds, it nevertheless gave rise also to what has come to be named rather euphemistically *linguistic transparency* as postulated both in cognitive psychology and cognitive linguistics.

Although this notion had been questioned since the advent of new connectionism [35] and has come under severe critique only recently for various reasons [60], it is surprising to find that the hypothetical character of the assumptions underlying the linguistic transparency postulate could have been overlooked, fallen into oblivion, or – for whatever reason – kept aside for quite a while. Thus, there was very sparse inquiry into how the postulated mental images, conceptual structures, or internal representations are constituted in the first place, i.e. which (adaptive, learning, emergent, etc.) processes do in fact enable a cognitive system to acquire these structures (propositional or whatever else may serve their purpose) and/or how their relatedness to the external world was established. Nor was there, in the second place, any serious interest – given the internal structures and their external relations were not considered innate, propositional, or else unquestionable, but instead subject to emergence and/or modification – to investigate how these structures (or those others that serve their purpose) can be (re)constructed or realized by procedural models of cognitive processing in language understanding. It simply did not occur to ask by way of which class of processes a material entity (sign structure) is not only *perceived* as such in order to be related to given internal models, but also *realized* in its (semiotic) functions which instead yield emergent internal representations.

Traditional models of *cognitive language information processing* (CLIP) do not answer questions that their designers had never been interested in until challenged by developments in the field applied to intelligence and language understanding [37, pp. 11]. What can nevertheless be derived as their response to the above problems, boils down to the general assumption that *knowledge* of various kinds[6] has to be postulated in order to let the cognitive processes operate the way they do in both, the natural system and its models. The obvious but unwarranted readiness to identify the properties of models (or *explicatum*) whose adequacy is pretended instead of tested, with features of the original (or *explicandum*) that ought to be isolated in order to

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

[6] This includes types of knowledge concerning the external world (*e.g. common sense*) and the sign systems employed (*e.g. languages*)

be explained, is one of the reasons that the so-called *cognitive paradigm* could not really be of help in overriding the presupposed mind/matter duality which keeps on to determine most procedural approaches to language understanding both in its rule based, symbolic, 'linguistically transparent' type, as well as in its pattern based, distributed, connectionist type of modeling.

Challenging this duality for the object of modeling (*natural language understanding*)[7], not, however, for the modeling activity (*repeatedly reproducible mediation*)[8], it will be argued that there are cognitive processes which not only cut across the distinction of mind and matter, but can even be considered to underlie and allow for this distinction. A class of these processes may be studied on the grounds of observable structures of natural language discourse in situated communicative interaction. These may procedurally be modeled given (and providing for) a possibility to distinguish an internal or *endo*- from an external or *exo*-view of reality which – in replacing the mind/matter duality – might (but need not) be identical.

2.2 Representations and Reality

In the context of disciplines focusing on aspects of cognition, like language philosophy, logics, linguistic semantics, biological neuro-science, and computational connectionism, it has been outlined [34] that the relationship between the real world or objective *reality* (R) of observable entities external to a cognitive system, and the perceptions of such observations which constitute that system's experience or subjective *actuality* (A), is cognitively as well as epistemologically highly relevant and model-theoretically most decisive. Suggestions for how this mediation relation may be (re-)constructed have resulted over the years in a number of types of models which range from simple identity as $A = R$, to functions as $A = f(R)$ depending on reality (R) only, or as $A = f(R, O, C)$ being based additionally on features of the observing system (O) and its cultural background (C), and reach out to structurally coupled resonance phenomena of semantically closed cognitive systems as $A_{t+1} = f(A_t, E, P)$ which relate perturbations (P) inflicted on the system from the outside, the structure of a state space (E) determining that system's possible states, to cope for the dynamic changes of the system's actual states A_t along a time scale. In this formula, A seemingly can do altogether without R [22]. This is a consequence of self-organizing, dynamic, autopoi-

7 As an object for the modeling enterprise, NL understanding is ambiguous: it applies likewise to the *processes* concerned as well as to their *results* whose mutual dependency has to be accounted for by adequate models. Clarifying the process/result ambiguity is to *analyze* and to *specify*: analyze in order to find the type of *structures* underlying the *results*, and to specify in order to determine the class of *processes* which will produce these *results*, before *procedures* can be devised whose implemented *instanciations* may qualify as realizing these *processes* which will operate on and, in turn, modify (old) and generate (new) *structures* as the *results* of NL understanding.

8 Empirical and procedural *models* serve their purpose by abstracting from irrelevant and by isolating relevant parts of the *original*, and by representing the interrelations, structures, functions, processes, etc. that characterize these parts in a format which allows *repetition* of processes, *reproduction* of results, and their inter-subjective *scrutiny* for concurrently forced agreement to its outcomes. Procedural and operational definitions of terms in experimental settings ensure the terms' employment in propositional expressions with space-time related falsification possibilities.

etic systems [21] for which the *observability* of entities external to a cognitive system hinges on their communicability to others which include internal results of commonly experienced external perturbations. Reality R, therefore, should be viewed more like a *situational* condition for the possibility of inter-subjective and social collections of experiential results rather than an independently existing sphere of entities [58]. Thus, suggesting and finding parameters to reconstruct the background of *experiential perception* for the interpretation of what can be considered *observable reality* in this way, underscores the importance of distinguishing *endo*- from *exo*-views of reality to replace the mind/matter duality in view of representations that – like natural languages – consist of entities whose observable reality provides for an experiential perception which is only the precondition for their *understanding* (and the modeling of it).

In the cognitive sciences, representations are taking a number of (even conflicting) functions which is the case with *mental models*. These either serve an explanatory purpose (allowing to understand how cognitive systems might manage to control complex input-output relations the way they do), or are in need of explanation themselves (as resulting from perceptions of the external world, and how these perceptions are transformed to gain a status of structures, which may be stored, identified, retrieved, and reactivated to serve the purpose they do). According to Johnson-Laird mental models play

> "a central and unifying role in representing objects, states of affairs, sequences of events, the way the world is, and the social and psychological activities of daily life. They enable individuals to make inferences and predictions, to understand phenomena, to decide what actions to take and to control its execution, and above all to experience events by proxy: they allow language to be used to create representations comparable to those deriving from direct acquaintance with the world; and they relate words to world by way of conception and perception." [18, p. 397]

The encompassing range of commitments listed here is but an illustration of the far reaching claims which mental models in cognitive science were expected to satisfy as internal representations of the external world both of the original/natural and the modeled/artificial cognitive system[9]. Apparently, these conditions were easily met as specified by the PSSH, so that symbolically formatted, propositional, language-like representations of conceptual systems (mind) formalized by logic-based calculi provided the interpreted structures whose interpretability did not seem to be in need of derivation or mediation[10] establishing their representational relation to what they stand for or symbolize (matter).

9 "In broad terms, a mental model is to be understood as a dynamic symbolic representation of external objects or events on the part of some natural or artificial cognitive system." [39, p. 9]

10 For a model of mediated interpretation, however, see Fig. 5, p. 375 below where a granular (set theoretical) decomposition is declared and a proper (relational) definition of *designation*, *denotation*, *description*, and *reference* is given as employed throughout this paper.

2.3 Knowledge and Memory

Following cognitive sciences, *knowledge* is the widely accepted precondition for the particular form and modus of information processing called cognition. It is assumed to operate on (informational) structures whose (descriptive, declarative, procedural, symbolic, subsymbolic, etc.) formats of adequately represented (world, common sense, tacit, language, linguistic, etc.) knowledge have been subject of an enduring discussion, enquiry and research since. The conception of addressable *memory* has been emphasized as the modular realization of knowledge structures. These are the results of prior processing or experience (retrievable when needed and modifiable when updated) ready to be activated by perceptual qualities of actual sensory data to yield new experiences. This view allows for the dynamism of memory structures and the mutability of knowledge representations as its informational content. However, cognitive modeling concentrated on realizing static formats of symbolic representations which were made available to the modeled system whose efficient performance calls upon it as retrievable from memory. This point gained some importance because the format of representing that knowledge not only determines the way how represented structures are processed but also what kind of structural properties can at all be dealt with[11]. In pursuing this line of thought, memory can be identified as the knowledge base whose format and structure of representation not only provides an *environment for thought* [63, pp. 101] but also the base for *meaning constitution* [41].

Following cognitive *linguistics* as being concerned with the (theoretical, formal, empirical, descriptive, normative, quantitative, procedural, etc.) analysis of natural languages, and linguistic *semanticists* in particular who are interested in how natural language expressions convey the meaning and informational contents they have, there is – by and large – some agreement on fundamentals that are fairly undisputed (although differently weighted in the wide spectrum of semantic theories). This accord appears to be based on the (minimal) assumption that language *signs* have (to have) *meanings* to let them be conveyed in *communication* among (natural or artificial) cognitive *systems* which need to have the *knowledge* to understand them. This wording of seemingly common sense trivialities nevertheless comprises a complex of multiply nested constraints and mutual dependencies which have been addressed under the notions of *situatedness* and *attunement*, *grounding* and *embodiment* introduced below (see pp. 355 and 359). These terms relate to central properties which apparently refer to several aspects of what in semiotics has been known as *semiosis*[12]. What appears to be the core problem of modeling language understanding as a cognitive process of

[11] Failing to combine the two branches of representational formats (rule-based, symbolic, declarative vs. pattern-based, numerical or subsymbolic, procedural) in knowledge representation and processing, will keep phenomena like *adaptivity, creativity, dynamics, emergence, learnability, variability, vagueness,* and *self-organization* outside the scope of what rule-based computing and symbol manipulation techniques have been able to achieve so far modeling automatic language processing (by way of *grammar formalisms, sentence parsing* techniques and *generation, deduction* and *inferencing* mechanisms). [50, pp. 248]

[12] According to Peirce, the three-way dependency he named *semiosis* of *sign, object,* and *interpretant* – as embodied in but not resolvable by relations like designation, denotation, or reference determining *signs, intensions* and *extensions* derived from Morris's semiotic trias – can only procedurally be enacted: "by *semiosis* I mean [. . .] an action, or influence, which is, or involves, a coöperation of *three* subjects, such as

meaning constitution can be specified as a cognitive system's *grounding* or an agent's *embodiment* (see pp. 358). Its semiotic features and its systems theoretical conditions go far beyond what model designers (of *disembodied* artificial cognitive systems) have mastered so far which people (as naturally *embodied* cognitive systems) have and apparently satisfy when using language expressions to communicate results of their cognitive processing successfully.

As traditional approaches consider disembodiment if not a prerequisite then at least an epistemological condition for the development of experimental models which are empirically testable, it might well turn out that only under this assumption natural and artificial cognitive language information processing systems (CLIP) can be defined as modular being composed of discernible strata of interacting subsystems. These have quite successfully been specified as knowledge of language signs (*vocabulary*), of structures of their combinability to form terms and strings of terms (*syntax*), of meanings of these terms and their compositions (*semantics*), and of how to employ all this adequately (*rules* and *patterns*) in situations (*pragmatics*). The hypothesis is that functional co-operation among these strata enables the CLIP system's successful conveyance of information to others (*communicating*)[13]. As most of these modules vary in bulk and condition, depending on co- and contextual constraints which are subject to changes of (individual, social, collective) knowledge that is permanently modified by cognitive performance (learning/forgetting, activity/idleness, etc.), the dynamism of multiply interacting dependencies poses severe problems not only (but essentially) to realistic semantics whose propositional conception of static knowledge, symbolic representations, and rule-based processing does not (yet) allow to cope with it adequately.

Having identified (formal) language to be central for this way of modeling approach to cognition, only the more pressing becomes the quest for answers to the many questions which (natural) language understanding poses but symbol systems – in presupposing the employed signs' meanings being understood – do not even allow to word.

3 The Systems Theoretical Frame

What has been termed the *Cartesian* [1] or *epistemic cut* [32] reflects upon the cognitive dilemma which the physicists' paradigm of scientific analyses produces whenever it is applied to CLIP systems. These require – unlike complex dynamic systems in physics – a form of "measurement, memory, and selection, none of which are functionally describable by physical laws that ... are based on energy, time, and rates

sign, its object, and its interpretant, this tri-relative influence not being in any way resolvable into actions between pairs." ([33, p.282]

[13] Note, that the notion (and problem) of *understanding* does not occur anymore because the *meaning* of NL expressions had been – in Tarski's tradition [64] – either transformed [65] via displacement by formally defined truth functions and their (tabular) evaluation, or dissolved [7] via formal expressions of truth conditions encoding their informational content in symbols. Both, symbolic encoding and evaluation of truth, however, presuppose prior (embodied) understanding.

of change." [32]. The argument is again about what realists [36] call reality and its representations [60] and how the partition which separates (observable) objects or entities from the (observing) system which perceives them and brings about such a partitioning, can be understood more as a result of the system's cognitive activities rather than a presupposition to them. The scope of questions narrows down on how the relation between the system and its embedding environment can be made the basis it probably provides for the analyses of cognitive processes. This relation which underlies such notions like *grounding* and *embodiment*, *attunement* and *situatedness* appears to be central also for a more adequate understanding of signs, symbols, and languages, and what their communicative employment creates and presents rather than represents and depicts. Understanding language understanding from a systems theoretical perspective will hopefully improve the modeling too that has to be developed for processes which constitute *understanding* as a form of learning, and which are yet more enigmatic than well understood.

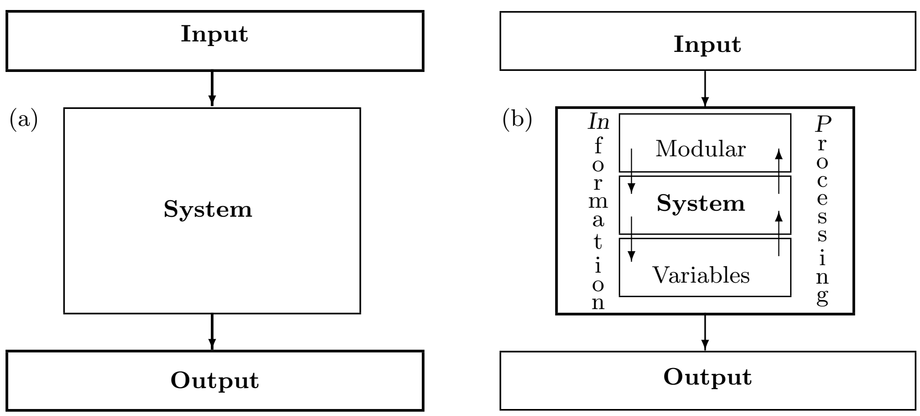

Fig. 1. The external model of a system (a) considers the system's behavioral characteristics, i.e. the way how it performs in processing (some controlled or known) *input* and produces (observable or measurable) *output*. The internal model (b) characterizing the system's structural properties, i.e. the number and kind of its modules and variables in the system, and how these are connected and interact.

3.1 Grounding and Embodiment

In *systems theory*, it is common practice and in accordance with epistemological realism to presuppose objective reality and conceive of systems which perceive it in two ways:

- *externally* studied and characterized by their behavioral characteristics, i.e. the way how a system performs according to (controlled or known) data from environmental parameters as *input* and (observable or measurable) data as *output*, and
- *internally* by structural characteristics, i.e. the number and kinds of variables in the system, how these variables are connected to each other (forming modules) and how they interact.

Corresponding to this distinction – as illustrated by Fig. 1 – are *external* (a) and *internal* (b) types of models which both apparently abstract from the system's embeddedness into its environment, which is reduced to what the observable input and output will present.

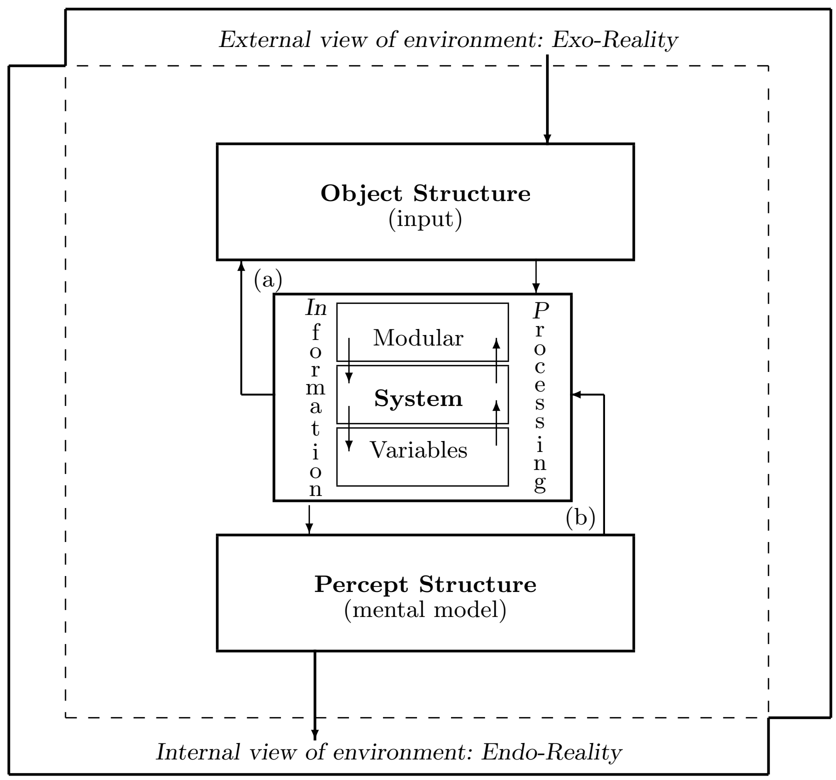

Fig. 2. Situatedness of a cognitive information processing system whose *percept structure* or mental image (i.e. the internal view or *endo-reality*) of its environment is allowed to differ from what that environment's *object structure* (i.e. the external view or *exo-reality*) looks like (e.g. for an external observer or the model designer). This is illustrated by the two interlocked feedback loops connecting (a) object structure and system and (b) system and percept structure. Thus, the *input* of perturbations from exo-reality is dynamically related to its internal representations of *mental models* whose collection make up the system's endo-reality.

In many cases, such a reduction is indeed indicated and well suited, provided the model designers knowledge (of external environmental constraints and/or internal systemic architectures) is sufficiently certain and reliably precise to model a system's respective internal processing or external behavior. In cases where this knowledge either cannot be assumed or is disputed and not well understood, research is most advised to investigate its conditions and to look for processes which might ground, if not generate it. In model theoretic semantics and its employment in *cognitive language information processing* (CLIP), this chance is far too often missed[14]. Even approaches

[14] A notable exception is again *Situation Semantics*: "It is fairly common practice in mathematical semantics simply to identify the world with the structure that represents it. But this identification hides an important

which combine the system's modular organization (b) and its observable performance (a) do not suffice unless, of course, the focus is on the system's interaction with its environment constituting the *system-environment* (SE) relation.

Putting the system back (as illustrated schematically by Fig. 2) and restoring the SE relation is tantamount to a relaxation – if not even an abandonment – of the notion of processing predefined *input data* in favor of an environmental signal and data flow of perturbations. Out of these an *object structure* is to be generated and derived (feedback loop *a*) as perceived and processed according to the system's own structuredness and capabilities, rather than the model designer's knowledge and understanding of what the system's environment looks like. This is what system theorists have termed a system's *grounding*[15] and *embodiment* which certainly amounts to a revision of the mind/matter division and will prove to be preconditional for adequate understanding of (cognitive) processes of language understanding. However, this is only in exchange for a bunch of problems which concern as yet unsolved questions of how to (re)present and interpret *grounded* models' results, and how to evaluate, test, and decide what can be considered intrinsically 'meaningful' to the modeled system. Furthermore, as the results of the system's internal processing (feedback loop *b*) and its *mental image* or *percept structure* need not be identical to, or converge on the *object structures* in its environment as perceived by an external observer (or the SE model designer), provisions have to be made to allow for the modeled system's internal view or *endo-reality* to divert from the external view of the environment or *exo-reality* (overlapping squares in Fig. 2).

It has to be noted, though, that percept structures – albeit a result of input processing and hence a form of output – have not to be externalized (as Fig. 2 might suggest). Their separation is merely to indicate a difference of the system's experience resulting in a percept structure (*knowledge what*) which is (re)presented in some format distinct from other results of processing that present themselves as a change of the system's internal state (*knowledge how*). Although both are internal to the system, the latter is without alternative whereas the former, when stored in separately structured memory modules for (identifiable and selective) retrieval, allows for this very possibility of alternative system states being invoked by (internal) memory representations rather than by external perturbations. With respect to evolutionary systems, the complementary functions – classification fulfilled in acts of *measurement* which serve to interpret the meanings of their *representation* – have been identified as an epistemological necessity [29, p.270] based upon the *semantic closure*[16] which is at the base of what we call the *semiotic* dimension of cognition. Without it, knowledge

aspect of the whole endeavor, [. . .] This is why we explicitly distinguish real situations from abstract ones that accurately *classify* real situations." [3, p. 57]

[15] "The grounding problem is [. . .] of how to causally connect an artificial agent with its environment such that the agent's behaviour, as well as the mechanisms, representations, etc. underlying it, can be intrinsic and *meaningful to itself*, rather than dependent on an external designer or observer." [72, p.177, my italics]

[16] "The semantic closure principle allows us to treat the *action* of a measuring device as primitive because the details of its construction are accounted for by a [. . . representation], while the *meaning* of the [. . . representation] can be treated as primitive because the details of the interpretation are accounted for by a set of measuring devices." [29, p.275]

of (results of) perturbations or events would be indistinguishable from the (experience of these) perturbations themselves, and likewise there would be no need for representations, selectively identifiable from memory as a result of (temporally and/or locally) remote (knowledge of) experienced events.

It should also be noted that the correspondence between the system theoretical input-output relation and the object-percept relation as resulting from cognitive processing, is due to multiple processing loops which incrementally establish the similitude that allows for that analogy to be drawn. However, it is only by the concomitant separation of the system's processing in two interlocked feed-back loops, *a*) by processing input which results in states of perception of the object structure, and *b*) in processing these states which result in the output percept structure, that the distinction of processes of *adaptation* from processes of *learning* are reasonable. Thus, relating object input and percept output, *cognition* can be understood as an incremental *learning process* of constraint based information feedback which approximates object and percept structures under operational restrictions that the system's internal and the environment's external organization determine.

The transformation from a flow of perturbations (input) to the perception of an environmental object structure appears to be a consequence of and dependent on the system's processing capabilities rather than a feature solely based on the environmental conditions external to the system. The notion of grounded or embodied cognition accounts for this transformation by the definition of general constraints for the *measurement* of environmental perturbations and the *representation* of its results assumed to hold for all types of situated (cognitive) information processing. It may be characterized in a rough and informal way by the two feedback loops (*a*) and (b) (Fig. 2) of interlocked information processing in the system:

- *measurement*: segmenting and identifying information from multi-sensory perturbations processed by feedback loop (*a*), leading to the constitution of transient *object structures*, based on
- *processing*: comparing and combining information in multi-level interaction of modular, *interlocked* feedback loops (*a*) and (*b*), augmented by
- *representation*: classifying and organizing mental images as mutable results from modular processing by feedback loop (*b*) in dynamic memory or evolving *percept structures*, due to
- *situatedness*: the system-environment relatedness whose 'reality' is constituted as an overlap of (not necessarily converging) external views of *object structure* (input) or *exo-reality*, and of internal views of *percept structure* (mental models) or *endo-reality*.

To bring home this point, *cognition* can well be characterized as knowledge based and memory dependent. This implies, however, that knowledge may also be represented in other than symbolic structures, and that memory need not be a separable module but can also consist of the system's state changes. Giving up the pre-established boundary between real-world objects and their system-dependent perception as symbol based mediation fostered by realistic models of cognition, and substituting it by processes which relate system and environment as their mutual *situatedness*, opens up a modeling perspective which allows to account for (some of) the cognitive complexities that language understanding still presents. In procedural models[17] such processes can be devised to produce computable results whose visualizations – either based upon a system's internal state changes or its memory module structure and organization, or both – may converge on an *endo/exo*-distinction that is the result rather than the presupposition of cognitive processing.

3.2 Situatedness and Attunement

Knowledge-based or *cognitive* information processing systems will qualify as *dynamic* whenever the situational processing of environmental input is conditioned by constraints which prior processing has established and which present processing will modify or cancel, replace or renew in order to condition future processing. Such processing constraints can either be a *mutable* component of the system's processing structure or a *variable* consequence of the system's percept organization. These may either be embodied in the system's transient states of information processing which integrate the traces of prior processing and experience, or be represented – other than by the system's own status of processing – in some separate structure whose formatted storage would comply with what constitutes *memory*. This very general characterization of *cognition* approximates the system theoretical characterization of *life* which is, of course, not accidental. It is worth noting, though, that due to the primacy of the embeddedness (SE relation) termed *situatedness*, a cognitive system's memory is a *sine qua non* condition for knowledge acquisition or *learning*, and a corresponding mediation of any anticipatory behavior or planning, deciding, and performing of actions (spatially and temporally) independent from (immediate) stimuli of environmental perturbations.

Originally introduced as the *pragmatic* dimension in general semiotics, the notion of *situatedness* focuses on the relatedness of system, environment, and the processing concerned. It characterizes in an abstracting way the conditions that mutually constitute the restrictions on what (of the environment) can how (by the system) be realized or experienced. More specifically, the system's dependency on the knowledge of constraints as *mediated* by its awareness or the system's attunement, is complemented by the structural organization responsible for the system's *immediate* perception of environmental conditions constituting its adaptation. Both, *attunement* and *adaptation*[18] are thus conditional for the systems' optimized performance (and/or

[17] Roughly, these are models whose object entities essentially are represented as and defined by *procedures*. Other than symbolically represented propositions defining (crisp and/or soft) categories, procedures are formal notations of *processes* (abstracted from their timeliness) which can ideally be algorithmized in order to be implemented as programs to run in computers (in time again) and operate on data structures yielding results which alter these structures and hence may be observed as being changed in their (spatial and/or temporal) appearance. (see also pp. 381)

[18] While *attunement* specifies a system's abstract type of awareness or knowledge of constraints which hold and apply in a situation discriminating it from others, the notion of *adaptation* will characterize the state of structural restrictions which determine a system's behavior most adequate to its environmental conditions.

long term survival[19]). They can be assumed to hold for all information processing in (natural/artificial) living systems in the sense that cognitive processing cannot be abstracted and freed from its situatedness [5].

The generality of *situatedness* and its grounding quality for cognitive language information processing systems to structure reality led semanticists to adopt this notion as fundamental. In model theoretic semantics it serves to allow for a communication based formal treatment of natural language meaning [3,12] and possible applications [2,10]. What in the sequel we shall refer to as *situation semantics theory* (SST) is concerned with the development of a theory of information content or *situated logic* [11] which accounts for the constraints that contextual (i.e. situational or pragmatic) features of information processing produce. These constraints comply with the assumption, that beside spatial extension and temporal duration, it is the fundamental relatedness of situations whose regularities – whether or not these have been tacitly implied, explicitly included, or even parameterized in a model – trigger the signaling function for data to be identified as relevant for processing by an information system embedded in its environment.

> The agent-relative framework that 'picks-out' the ontology is referred to as the *scheme of individuation* ... That is to say, in our study of activity (both physical and cognitive) of a particular agent or species of agent, we notice that there are certain regularities or *uniformities* that the agent either individuates or discriminates in his behavior. For instance, people individuate certain parts of reality as *objects* ('individuals' in our theory), and their behavior can vary in a systematic way according to spatial location, time, and the nature of the immediate *environment* (the 'situation type' in our theory). [11, p. 81]

In a realistic perspective, this view of situatedness makes the concept of *infon* – which is meant to denote a basic and abstract item of information[20] – carry the coincidental burden of being both, independent of an information system and constituted by its processing. Evading this contradictory conception, our notion of situatedness can be understood instead as a direct consequence of life and living systems [30] accounting for their *being-in-the-world*[21] that underlies – bar none – any process of cognition. As these situated processes can hopefully be accounted for by an (implementable) type of procedural model that realizes such processes rather than abstract and represent components of them symbolically for subsequent (rule-based) manipulation as in model theory, the concept of *infons* can be dispensed with in exchange for an elaborated concept of *situatedness* which allows to locate *adaptation* and *attunement*.

[19] This is one of the reasons why an ecological perspective [4] on information processing and cognition [13] is followed here and in [54,57].

[20] "Though the ontological existence of the various constituents of an infon depend on their being picked out by the individuation scheme, the information about the world encapsulated by an infon has the status of *being* information quite independently of an agent or any scheme of individuation. That is to say, an infon is a fact (i.e. informational) simply by virtue of the way the world is." [11, p. 84]

[21] The term is meant to relate to HEIDEGGER's philosophy of existence [16, pp. 49] where the conditions for grounding and the possibilities for the constitution of experience (*fundamental ontology*) are analyzed.

The particular forms of cognitive processing which deal with a segment of real-world structures that cannot sufficiently be characterized by their inter-subjective observability or their extension in space and time alone, have to be accommodated in system theoretical terms. When such bivalent entities like *signs* come into focus, the *cognitive* processes concerned which have been identified to constitute the SE relation of situatedness above (Fig. 2), discriminate clearly between such entities' *immediate* perception as evolving real world objects, and their *mediate* understanding as signs (like natural language structures) (re)presenting something else, which renders the cognitive processes *semiotic*. The distinction concerns the quality or function these entities have beyond their immediate perceptibility as real-world objects which can be modeled accordingly. In addition to and depending on that immediacy, however, these entities have (or acquire) a function which discriminates them and – due to their *situatedness* together with the system's concerned *adaptation* and *attunement* – transcends their immediacy or object structure. This function enables them to present and (re)present some entity of different ontological value as its mediation[22]. Whereas most objects have some functions in situations anyway, signs apparently owe their existence and observable space-time extension solely their obligation to enable inter-subjective mediation, i.e. to transcend their factual object character in order to constitute something we call *meaning* whose modus of processing is *understanding*[23]. Corresponding to this two-level ontology of signs is the system-environment relation being composed of the two interlocked situational cycles of processing (Fig. 3). While *cognitive information processing* is concerned with the observability of natural language discourse analogous to the knowledge based evolution of object structures from a flow of environmental perturbations (a), *semiotic cognitive information processing* is concerned with the constitution of meaning analogous to the knowledge based evolution of percept structures from a flow of natural language signs whose semantic values are direct (re)presentations of system-environment constraints as semantic space structure (b).

3.3 Mediate and Immediate

As outlined above, CLIP approaches presuppose the semiotic function of meaning constitution, but do not model it. In order to cope with this function more adequately, the *semiotic cognitive information processing* (SCIP) model extends the system-environment relatedness to become in fact a triadic one of system, discourse, and semantic space structures (Fig. 3). The external view (*exo-reality*) of a system's

[22] The photograph of a slice of bread is a *picture* that can be perceived and normally also interpreted, the string of letters 'Brotschnitte' can be perceived as a 12 letter *word* which is understood only due to proper attunement. Both objects, *picture* and *word* have to be recognized and constituted in order to refer to some other object whose particular space-time extension as a real-world *slice of bread* may render it – even without optical identification or linguistic label – part of a (not necessarily cognitive) factual situation in which – other than the imaging picture and the designating word – it can be eaten to stop hunger.

[23] In natural language communication this is a common experience for nearly all interlocutors: generally, what we have understood (as its contents) in a conversation, from a text read, etc. is remembered much more easily than the particular object structures of wording, sentences, etc. by which these meanings have been conveyed, exceptions allowed. Other than recognition of acoustic and optic phenomena, memorizing discourse is primarily contents driven and meaning constitutional.

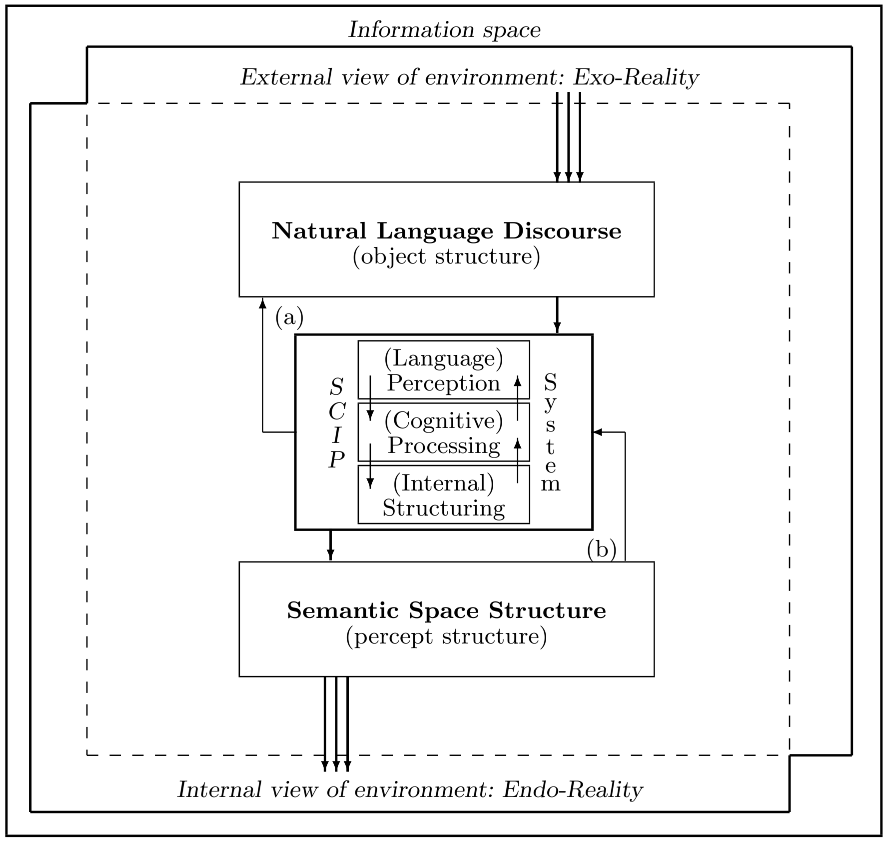

Fig. 3. The situational setting of a SCIP system-environment relation within information space which is segmented by the informational content of the natural language discourse. This segment is allowed to yield divergent percept structures as created by external observers of the system's environment (i.e. *Exo-Reality*) and by the system's own view of it (i.e. *Endo-Reality*). This is due to the processing of the PHT corpus of **natural language discourse** which serves as *structural coupling* between the environment and the system. The SCIP **system**'s limited *perception, processing, structuring* capabilities (*attunement*) constitute the **semantic space structure** (*percept structure*) as an intensional representation (*knowledge*) of what the system realizes of its environment (*understanding*).

environment, as well as the internal view (*endo-reality*) which the system develops of that environment, are both segmental parts of *information space*. These parts, however, are the results of (cognitive) processing (a) of a very particular kind of environmental object structure or sign agglomeration perceived as *natural language discourse*, whose (semiotic) processing (b) leads to a percept structure represented as *semantic space*. This is very much like that of ordinary objects apart from being virtual compared to that rooted in immediately observed environments, and brought about by the SCIP system's interlocked feedback loops (a) and (b) as a form of mediation.

> "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 the 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".[24] [57, p.163]

Accordingly, *immediate* or space-time-identical system-environments without intermediate representational form may well be distinguished from *mediate* or space-time-suspended system-environments whose particular representational import (as in NL *texts*) corresponds to their particular bivalent timely status both, as long-term types (composed of language *signs* whose feature to have understandable *meaning* is not directly observable), and as short-term tokens (directly observable and in need of being *(re)cognized* in order to be *understood*)[25]. This double identity calls for a particular modus of actualization (*understanding*) that may be characterized for systems appropriately adapted and attuned 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.*

Hence, in accordance with SST and 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 artificial) information processing system beyond reality's material manifestations. This extension applies to both, the *immediate* and the *mediate* relations a system may establish according to its own evolved adaptedness (i.e. innate or given, and acquired or evolved) *structuredness*, processing *capabilities*, and *knowledge* representations.

[24] This allows for the conception of different *linear* time scales extended to that of differently scaled time *cycles*, particularly in view of the resolutional power of representations and their semiotic processing in computational models – as addressed below (pp. 376: Eqn. (9), Fig. 5, and pp. 380: Eqn. (14), Fig. 6).

[25] In view of natural languages discourse there is yet another distinction to be made, 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 spatially relaxed (e.g. videophone conversation), the latter or scripture based interaction will generally dispense with the time coordinates' identity of system-environment pairs concerned, depending on spatial identity of material media (e.g. papyri, mural inscriptions, letters, books, etc.).

In a (re)constructive stance of cognitive modeling this is tantamount to find implementable procedures for a kind of cognitive information processing which is based on the system's intrinsic structuredness and at the same time tied to its perception of the extrinsic environment, both being subject to change. In this perspective, identification and interpretation of external structures can be conceived dynamically as a property of double feedback in ecological information processing which (natural or artificial) systems – due to their own structuredness – are (or ought to be) able to perform: processing information which is *cognitive* as being based on knowledge structures, and *dynamic* as these structures get modified by processing constituting *learning*.

4 Computational Semiotics

Semiotics as the *general theory of signs* goes back to Charles Sanders Peirce (1839–1924) who laid the foundations in his philosophical and theoretical writings [15] on the triadic ontology (*1st-, 2nd-* and *3rd-ness*) of signs and their communicative use in the latter's functional trias (*index, icon, symbol*). The three dimensional theory of signs [26] (*syntactics, semantics, pragmatics*) is commonly tied to Charles William Morris (1901–1979) who inspired the more descriptive and empirical development of semiotics since the thirties of the last century, resulting in the multitude of directions in contemporary semiotic study since. Ferdinand de Saussure (1857–1913), may be credited with the introduction of an holistic notion to the study of signs and languages [62] claiming that – particularly for linguistics as part of semiotics (*sémiologie*) – all language analysis ought to be directed towards the identification of the *systematic* relatedness of functions of language structures (*langue*) rather than towards signs and structures in isolation. Abstracted from and based upon regularities observable in the formation of signs and sign aggregates, the system underlying all natural languages appears to be constituted by an elementary two-level relatedness of linear *syntagmatic* order (*syntagmes*) and selective *paradigmatic* grouping (*associations*) of signs and strings of signs in recurrent cotexts[26] of performative language use (*parole*). These findings – though later refined and in turn modified – proved to be fundamental for the structural paradigm in modern linguistics since.

Following the *semiotic paradigm* in natural language semantics as postulated decades ago [41] can make a whole range of phenomena subject to linguistic investigation which – like vagueness and variability, adaptivity and dynamics, learnability and emergence of meaning – had been (and for some semanticists still are) excluded from the scope of linguistic enquiry and its focus of interest. For generative and unification-based grammatical approaches to natural language phenomena, as for philosophically motivated logical analyses within model-theoretic approaches to natural language meaning, the predominant study of language consists in the rule-based identification of structures and the symbol-based manipulation of their representations. Thus, truth-functional explication of linguistic constructs as abstracted from language dis-

[26] Linguists distinguish *cotext* or the material embedding of language items within discourse from their *context* or the situational environment of (items and) discourse as determined by their use in communication.

course and represented symbolically by formal language expressions, have long outclassed and overshadowed any advances in numerical, subsymbolic, pattern-based, and perception-oriented approaches to natural language analysis.

4.1 Semiotic Cognitive Information Processing

Only recently have procedural models in *computational semiotics* (CS) succeeded in devising some functional (re)construction of implementable processes of meaning constitution. They have come up with computational means to simulate – or even realize[27] – in software systems the way how meaning might be understood. Natural (and artificial) cognitive systems endowed with such processing capabilities which seem to be responsible not only for the *understanding* of language signs as meaningful, but also for the constitution of *meaning* as a form of inner/outer mediation, can well be identified as *semiotic*. Any *semiotic cognitive information processing* (SCIP) system, therefore, will have to be modeled as being capable of meaning constitution/understanding from processing natural language discourse whose results may be studied – as it were empirically, albeit indirectly – via implementations of algorithmized procedures and the structures they produce in an observable and controlled way.

It has been shown elsewhere [52–54,56] that an experimental setting based upon the quantitative analyses of structures of natural language discourse can offer some exceptionally seminal insights into SCIP system performance. This is due to the fact that collections of pragmatically homogeneous texts (PHT-corpora[28]) provide sufficient structural information whose relational constraints of linguistic structures and what they stand for can very effectively be exploited on that *corporate* level [42,51,23].

Text-based quantitative analyses of PHT corpora suggest and allow to develop procedural models for cognitive processes of language understanding. These employ reconstructive means other than in traditional linguistic approaches. While the latter are propositional in scope, focusing on linguistic structures up to the sentence level whose syntactically correct and semantically true formal reconstructions of typified phrase structure and sentence formation is considered a prerequisite to language understanding, the former approaches are based on structures other than and beyond the sentence boundary. They use procedures instead of categorial descriptions to define the entities in models that enact rather than describe processes of self-organization believed to underlie language understanding. These processes generate as their result relational representations which qualify to be named *semiotic* because in artificial SCIP systems they can be made to function (very much) like conceptual structures

[27] The necessity to distinguish sharply between *simulation* and *realization* in modeling ecological systems was clarified in desirable detail by Pattee [30] and may be related to the even more fundamental issue addressed by Casti [8] 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.

[28] A corpus of *pragmatically homogeneous texts* consists of discourse which can be considered a random sample from the (virtual) population of (situated) natural language expressions that have (or could have) been produced by interlocutors for communicative purposes in a (specified) situation of verbal interaction.

or internal models (see pp. 352) as hypothesized by cognitive science for natural and artificial CLIP systems.

The dynamics of SCIP models depends essentially on their format of non-symbolic, distributed representations whose processing allow new representations to emerge as a multi-leveled form of self-organization. These emergent representations are tying the system to those segments of the real world which the language expressions are a part of and – when processed properly – convey information about as SE relations or their meanings. They do so both, according to their grammaticality and propositional contents *external* to the system in the above specified sense, a n d according to the system's own or *internal* understanding which can be learned from the non-propositional, syntagmatic and paradigmatic regularities in textual structures and may be visualized accordingly[29]. This is achieved by formalizing these SE ties not as functions abstracted from grammatical rules that are represented symbolically, but as a class of restrictions that are typified by (soft) constraints, modeled as procedures that produce (fuzzy) relations represented as (type-value) distributions. Resulting from computation, these are not another instance of transformed data representation but a new type of structural representation associating emergent entities (concepts) with observable entities (objects/signs) to realize what may be named *understanding*. The typified (soft) constraints are instantiated by procedures which operate on labeled linguistic structures and even allow to combine, mediate, and unify traditional (crisp) strata of cognitive investigation and categorial linguistic language analysis. It is the semiotic shift of perspective which thus replaces, or rather, complements formal definitions of symbolically represented (linguistic) entities by computable processes which make these (and other) entities emerge from structured (language) data as constrained (fuzzy) relations represented accordingly, without any other definition than the procedures which generate them. This procedural paradigm justifies to subsume such modeling approaches to natural language understanding under the name of *computational semiotics*.

4.2 Computational Semiotics and SCIP

Computational semiotics neither depends on rule-based or symbolic formats for (linguistic) knowledge representations, nor does it subscribe to the notion of (world)

[29] However, it should be noted that the contents conveyed cannot always be represented in a language independent way, i.e. by observable operations presented without being understood prior to their (re)presentation. This is why traditional cognitive approaches readily accept a linguistic analysis of propositional language structure as an explication of understanding, and why linguistic semantics in turn appeals to formal logics as an available format for representing NL expressions' propositional functioning. Furthermore, this might be the reason also why the truth functional analysis of propositions can be said to provide an adequate notation for what can be understood as the referential meaning or content of a declarative NL sentence expressing that proposition. And this is, finally, why – for the experimental testing of the modeled SCIP system – we have taken recourse to simple well defined real world situations which can referentially be described by collections of texts of NL sentences that are semantically true. Assembled in a PHT corpus, these texts form the basis for the meaning constituting algorithms implemented to realize the SCIP system's understanding of the texts (the result of) which can be visualized and compared to the (experimental) real world situation, not [!] to a representation of it. (For an implementation, see `http://www.ldv.uni-trier.de:8080/rieger/SCIP.html` shortly).

knowledge as some static and given 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 for which algorithms can be found that can be implemented and made to operate. In particular, the emergence of structures as a meaning constitutive process is studied on the basis of combinatorial and selective constraints universal to all natural languages. This is achieved by processing multi-resolutionally formatted representations [24] of *situational* constraints[30] within the frame of an ecological information processing paradigm [54].

These types of constraints appear to be general enough to be imposed contingently both, on material forms of observable entities (e.g. sign structures), and on particular settings in which these entities are observed (e.g. situation structures). Thus, (linguistic) entity and structure formation as well as (semiotic) sign and symbol function may 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. This is an extension to traditional linguistic analyses which have long – however coarsely – identified and represented their findings as *morpho-phonemic*, *lexico-semantic*, *phraseo-syntactic* and *situational* or *pragma-semantic* types of structures. In *fuzzy linguistics*[31] (FL) these 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[32]. 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 representations on different levels may be understood as the semiotic system's (hidden) layers of information processing, the system's own (internal) structuredness – which may (in parts) be visualized diagramatically – would represent its state of adaptation to the (external) structures of its environment as perceived and mediated by the natural language discourse processed.

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

[30] "*Constraints* give rise to *meaning*; attunement to constraints make life possible. Some constraints are unconditional or *ubiquitous*, holding at every location [...]. Others are *conditional*, holding only under certain special circumstances or conditions. Attunement to conditional constraints is as important to an organism's interaction with the environment as is attunement to ubiquitous constraints." [3, p.94, my *italics*]

[31] The FL approach to natural language analysis has recently been characterized [45,55] as an extension to *computational linguistics* (CL) based on the empirical investigation of performative language data in large text corpora. Its findings are represented and processed employing FST and techniques of fuzzy modeling to achieve higher adequacy of linguistic models than those inspired by competence theoretic approaches.

[32] "It is important to realize that *controls* must operate between different descriptive levels, just as *constraints* must be defined by different descriptive levels. This is necessarily the case for all measurement, recording, classification, decision-making, and informational processes in which a number of alternatives on one level of description is reduced by some evaluative procedure at a higher level of description." [28, p. 251]

processing. It simultaneously constitutes meaning by exploiting constraints that are interpretable for properly attuned SCIP systems [57].

4.3 Language Understanding as Meaning Constitution

For cognitive models of natural language processing, *understanding* natural language discourse has always been conditional and a prerequisite to research. In what we have termed *computational semiotics* [55], situated natural language discourse in the form of PHT corpora has been made the analyzable and empirically accessible evidence for tracing such processes of language understanding or meaning constitution as a form of perception-based *learning*. In this sense, another *semiotic* dimension is added to *cognitive information processing* of signs and symbols which renders it evolving. This dimension is well exemplified by humans' outstanding language learning and meaning acquisition capabilities allowing to generate, manipulate, and understand new language aggregates. We all experience that faculty quite naturally and permanently while communicating with each other. Even as external observers ignorant of a particular language we may recognize some of it witnessing interlocutors who employ physically traceable language material of written or spoken words, phrases, texts in discourse. Thus, natural language discourse might reveal essential parts of the particularly structured, multi-layered information representation and processing *potential* to a system's analyzer and model constructor in rather the same way as this potential is accessible to an information processing system trying to understand these texts[33].

In *information systems theory*, situated SE relations (comprising *system, environment*, and *processing*) are considered *cognitive* inasmuch as the system's internal (formal and procedural) knowledge applied to identify and recognize structures external to the system is derived from former processes of environmental structure identification and interpretation. Situated cognitive SE relations become *semiotic* whenever this knowledge applied to recognize and interpret structured entities is based on or directed to object structures which are (representations of) results of self-organizing interlocked feedback processes through different levels of (inter-)mediate representation and/or emerging structuredness. This may be illustrated by the complexities of natural languages due to the double ontology of signs and symbols as aggregated – both syntagmatically and paradigmatically – in situated discourse.

According to *Situation Semantics* [3] any natural 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. In systems theoretical terms, this translates to *meaning* as 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 environments (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

[33] For the discussion of important differences see [57, p.167]

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, and represented accordingly. 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*.

For SCIP systems, such uniformities appear to be signaled by natural language sign-*types* whose employment as sign-*tokens* in texts exhibit a form of *structurally conditioned* constraints. Taking the entity *word* as a componential example for 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 employed. Thus, as a means for the *intensional* characterization (as opposed to the *extensional* description) which constitute the *situatedness* of *mediated* SE relations by way of NL discourse, the regularities of word-usages serve as an access to and a representational format for those elastic constraints which underlie and condition any word-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.

Moreover, in accord with Peirce's characterization of *semiosis* as a triadic relation[34], the SCIP systems' view allows to integrate different ontological abstractions of *language*

- as a material component (*sign*) in a system's external environment, i.e. *discourse* observable at a physical space-time location;
- as a constituent of virtuality which systems properly attuned experience and recognize 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 which determine *understanding* as the constitution of the meanings conveyed.

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 *meaning constitution* or *understanding* as a form of *learning*. 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*.

[34] "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." [33, p.282]

5 Language Structures

Although language philosophy and logics, information science and artificial intelligence, psychology and linguistics, and many other cognitive science disciplines [37] have attempted to contribute, unraveling (at least some of) the complexities inherent in the phenomenon of cognition under recourse to propositional language structures, it may be more promising to investigate, inversely, what the perception-based analysis of structures of performative language use – other than their propositional analyses – might contribute to the understanding of the role cognition plays in modeling language understanding. Such a (hopefully more adequate) model could allow for experimental tests of its results of (non-propositional) understanding of texts against the observable structures of the real world as described by true propositions expressed in natural language sentences from these texts. As both these (world and language) structures have spurred interdisciplinary hypothesizing for some time now, the (overt and hidden) functions which aggregates of language signs (words, phrases, sentences, texts, etc.) in discourse exhibit, are far from being well understood yet. In the course of research, only a few were (partly) identified and analyzed, their conditions examined, and their possibilities determined as to what extent they can – in a general and abstract way – be characterized as *constraints* allowing these functions to serve their purposes the way they do.

5.1 Constraints and Situations

The functional view of languages reveals that only by restricting the number of theoretically possible alternatives to a limited number of realizations establishes what we perceive as regularity or structure both of processes and their results. The perception of observable regularity and structure in language expressions need not be identical with the ability to identify and characterize the processes underlying them, let alone to (re)present these as procedures, as formulation of rules or even laws[35]. The general notion of language *constraint*, however, serves to designate the abstract type of restrictions which may very differently be realized to create order in very different possible alternatives within limited and specifiable situations. In this perspective, constraints may be considered the unifying heritage that all natural languages the world over have developed (*diachronically*) over many generations and centuries in optimizing (*synchronically*) their means to enable successful verbal communication by the performative uses of language structures and their optimization. It is due to these constraints realized in processes which produce observable structures that today we do not only distinguish linguistically different types and families of languages

[35] "The concept of natural *law* in physics is quite distinct from the concept of a *constraint*. A natural law is inexorable and incorporeal, whereas a constraint can be accidental or arbitrary and must have some distinct physical embodiment in the form of structure. [. . .] The reason that *constraints* [of motion] are not redundant or inconsistent with respect to the *laws* of motion is that they are *alternative descriptions* of the system. Constraints originate because of a different definition or classification of the system boundaries or system variables even though the equations of constraints may be in the same mathematical form as equations of motion. " [28, p. 250]

based on the structural differences these constraints and their manifestations exhibit, but that we also have become aware of some unifying features characteristic of all natural languages. It is only by these features that different observable structures can be identified to serve similar or even identical functions (*functional equivalence*) as (observable and testable) realization of constraints some of which might even be considered universal[36]. Being the results of operational optimization, these constraints – realized differently by different natural languages – provide sophisticated means (some of which have already been investigated by linguists and logicians) of functional diversity that allow interlocutors to communicate their cognitive results to others who are attuned to that language and understand it.

Following a *systems theoretical* view (see pp. 362) which allows to distinguish cognitive processing of environmental stimuli as immediate (signal) perception, from those resulting in mediated (sign/symbol) understanding, reveals that the highly functional and optimized constraints which are realized by language structures and instantiated in communicative discourse, enable a cognitive system to replace its (immediate) entity-observer relatedness of signal-based cognition by a (mediated) representation of it, or rather – to be more precise – by the sign/symbol based mediation of cognitive results that might (but need not) stem from immediate perception (or its derivatives)[37]. In establishing this (mediate) sign-interpreter or language-understander relation, a very particular *situation* is invoked which renders co- and contextual constraints effective that relax the cognitive system's dependence on primal observation and experience of environmental conditions which confine the immediacy of perception of language signs (and aggregates thereof). This relaxation, however, works only at the price of *situatedness*[38] which comprises the knowledge of both, the signs' presentational means that come as a cognitive system's awareness of or *attunement*[39] to these constraints, and the signs' representational import which comes as a cogni-

[36] Chomsky's dual conception of language (i.) as a multitude of (*ontogenetically*) conceivable *internalized* languages (IL) instantiating *universal grammar* "abstracted directly as a component [from the mental states and their physical representations of particular minds/brains] of the state attained" [9, p.26], and (ii.) as the collection of *externalized* languages (EL), borrowing the term not "to refer to any other notion of language . . . never characterized in any coherent way" (Chomsky, personal communication), but understood – in diverging from his view – to cover all (*phylogenetically*) possible phenomena of observable *language performance*, is an admittedly highly attractive one. However, it should not prompt us without examination to subscribe to unwarranted claims of the former's (IL) mental reality and the latter's (EL) "abstract objects of some kind". Instead, IL may well be understood as (systems of) principled features of *models* rather than properties of the *original* phenomenon of semiotic cognitive processing which is enacted in and constituted by observable communicative language performance.

[37] For more detail see [57, pp.162], where this replacement is introduced as a condition for a system's own (*intraneous*) experience being complemented by (*extraneous*) experiences made and communicated by other systems, hereby extending the semiotic systems' acquisition of knowledge and learning potential beyond identical space-time value pairs for processing system-environment (SE) relations.

[38] In SST situations are conceived both, as *real* and *abstract* entities to enable coverage of (*pragmatic*) issues of context, background, relatedness, etc. of language expressions and their informational import and semantic contents. "A *real situation* is a part of reality, individuated as a single entity according to some scheme of individuation. An *abstract situation* is a set-theoretical construct, a set of *infons*, built up out of entities called *relations, individuals, locations*, and *polarities*." [12, p.35]

[39] In *Situation Semantics* [3], *awareness* of, or *attunement* to a constraint is what enables a cognitive agent in a situation to infer that this situation is part of (or tied to) another situation. Attunement "does not

tive system's *grounding*[40] as being part of and embedded into the interaction with its environment, and makes (some) objects signs and their modus of perception understanding. Although all this semiotic *knowledge* has to be acquired somehow by experiential, attuned, situational, and grounded performance in order to be stored retrievably before becoming effective, this price has proved to be good value regarding the apparent (*ontogenetical*) superiority to other species' means of (*phylogenetical*) knowledge acquisition and transmission[41] which natural (and formal) languages and their mediating potential brought about for individuals, human society, and mankind.

5.2 Defining Meaning

For the sake of exposition we shall begin with the core notion of meaning. It may be conceived as something that ties together language expressions composed of signs, terms, strings, etc. and what they stand for (*designate, denote, refer to*) or convey as their content. Other than by PSSH, the quality which renders a physical object a sign or symbol – transcending its physicality by standing for some other (real or abstract) entity – is not just presupposed anymore, but has to be assumed an emergent and dynamically evolving property. It is exploitable by empirically testable, non-symbolic, text-based, and procedural means of modeling which symbolic, rule-based, and propositional analyses would not allow to attempt, let alone develop and implement. The algorithms to be found to instantiate that type of *semiotic* procedures will concomitantly determine a model of (emergent) results of such processing whose interpretability makes these (intermediate) structures part of the knowledge acquired which is representational of *understanding* or meaning constitution as *learning*.

Therefore, the focus of our investigation is on the tie that hooks certain physical objects to other physical objects which due to specific (co- and contextual) conditions acquire different ontological status (physical objects become signs) allowing to distinguish language elements $z \in V$ and what they mean, stand for or represent in the universe of discourse $x \in U$. This tie is realized by natural languages $\mathcal{L}$ which can formally be defined – based upon *fuzzy set theory* (FST) [67] – as a relation (not a function) $\mathcal{L} = V \times U$ that is general enough to allow for more than binary or crisp membership $(z, x) \in \mathcal{L}$. According to Zadeh [68, p.168] it can be characterized by the membership function

$$\mu_{\mathcal{L}} = V \times U \rightarrow [0, 1];\ 0 \leq \mu_{\mathcal{L}}(z, x) \leq 1 \tag{1}$$

as a fuzzy relation $\mathcal{L} = \{((z, x), \mu_{\mathcal{L}}(z, x))\}$ which induces for all $z_i \in V,\ x_k \in U,\ i, j = 1, \ldots, m; k = 1, \ldots, m \leq N$ a two-way correspondence (Fig. 4).

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require language [to be effective, but rather] amounts to a form of familiarity with, or behavioral adaptation to, the way the world operates." [12, p.91]

[40] It concerns informational content of a cognitive system's beliefs, desires, etc. "linking it to actual entities in the world in the appropriate manner." [12, p. 177]

[41] It even appears that the mediate-immediate distinction can serve to sharply differentiate between (sign based) *learning* and (signal based) *adaptation* of systems to their environment. Both require memory whose structures, however, are addressed differently: by signals for immediate evocation of state changes (adaptation), and by signs for mediated and/or virtual state changes (learning).

$$V \underset{dsc \subseteq \mathcal{L}^{-1}}{\overset{ref \subseteq \mathcal{L}}{\rightleftarrows}} U$$

Fig. 4. The (natural) language meaning $\mathcal{L} := V \times U \to [0, 1]$ as a fuzzy relation from aggregates T of *vocabulary* items $z \in T \subseteq V$ to collections X of elements $x \in X \subset U$ in the *universe* of discourse U declaring the two-way correspondence of meaning as reference ref relating T to X and description dsc as its inverse $\mathcal{L}^{-1}$.

Defined in accord with realistic semantic theory for aggregates T of language signs from the vocabulary $z_i \in T \subseteq V$ and collections X of entities in the universe of discourse $x_k \in X \subset U$, this two-way correspondence of $\mu_{\mathcal{L}}$ (Eqn. (1)) allows for a formal declaration of (natural) language *meaning* $\mathcal{M}$

- as (fuzzy) *reference* relation $ref \subseteq T \times X$, by restrictions from z into X producing (one-many) relations

$$\begin{aligned} R(z) = \quad & \mathcal{L}|z \quad = \mathcal{L} \cap (z \times X) \\ \Rightarrow \ & \mu_{\mathcal{L}}(x_k|z) = \{((z, x_1), \mu_{\mathcal{L}}(z, x_1)), \ldots, ((z, x_m), \mu_{\mathcal{L}}(z, x_m))\} \\ \text{for short} \quad & \{(x_k, \mu_{\mathcal{L}}(z, x_k))\} := \mathcal{M}_z \end{aligned} \tag{2}$$

  where $R(z)$ specifies the (fuzzy) extension $\mathcal{M}_z \subseteq X \subset U$, i e. the collection of entities in the universe of discourse which are being referred to (and to which degree) by $z \in T \subseteq V$, a n d *inversely*
- as (vague) *description* relation $dsc \subseteq X \times T$, by restrictions of x into V producing (many-one) relations

$$\begin{aligned} D(x) = \quad & \mathcal{L}^{-1}|x \quad = \mathcal{L}^{-1} \cap (x \times U) \\ \Rightarrow \ & \mu_{\mathcal{L}^{-1}}(z_i|x) = \{((x, z_1), \mu_{\mathcal{L}^{-1}}(x, z_1)), \ldots, ((x, z_m), \mu_{\mathcal{L}^{-1}}(x, z_m))\} \\ \text{for short} \quad & \{(z_i, \mu_{\mathcal{L}^{-1}}(x, z_i))\} := \mathcal{M}_x \end{aligned} \tag{3}$$

  where $D(x)$ specifies the (fuzzy) intension $\mathcal{M}_x \in T \subseteq V$, i.e. the *description set* of language signs from the vocabulary which contribute (and to which degree) to describe the entity $x \in X \subset U$.

Trying to apply these formula *in praxi*, however, is to encounter severe difficulties. In general, neither V and U nor $\mu_{\mathcal{L}}$ are known in their entirety, and only fragments of natural languages and of the universe are empirically accessible whose partly determined structures scarcely compensate for this lack. Also, numerical coefficients are yet to be found for the computation of membership values in (2) and (3) in a theoretically well founded way of NL reference semantics. These would allow to replace the (more or less) *ad hoc* and/or subjective estimates which so far prevail in representations of $\mathcal{M}_z$ and $\mathcal{M}_x$, by testable algorithms or operations that could empirically be evaluated. Although ZADEH's fuzzy referential models of NL meaning like *Possibilistic Relational Universal Fuzzy* (PRUF) [69] and *TestScore Semantics* (TSS) [70] are plausible and can indeed claim to have realized an operational working hypotheses [46], these and later developments do not yet provide a general solution that can be algorithmized and applied in processes of meaning constitution (i.e. *understanding*) by machine.

Earlier applications of FST to linguistic and NL semantics [40] had produced some evidence that $R(z)$ and $D(x)$ could not be assumed to be directly measurable or computable form texts. Therefore, the reconstruction of linguistic meaning relations was proposed [47] suggesting an empirical analysis of structural language constraints and their formal reconstruction as compositions of fuzzy relations. For these, numerical coefficients could be devised with computable algorithms for the electronic processing of masses of natural language texts which began to become available since the late seventies providing the necessary amounts of accessible data for statistical analyses [48].

5.3 Granular Decomposition

In order to achieve some terminological definiteness in modeling cognitive processes of language based understanding, some definitions shall be needed. They can be introduced along the line of information *granulation*[42] as a general form of relatedness or *granular* decomposition [46]. To start with, the core definition (Eqn. (1) and Fig. 4) of language $\mathcal{L}$ as a two-way relation provides for precision of its meaning $\mathcal{M}$ as *reference* and *description*

$$\mathcal{M} := \{ref, dsc\} \text{ where } \begin{cases} ref \subseteq T \times X \\ dsc \subseteq X \times T \end{cases} \tag{4}$$

As neither *ref* and *dsc* are directly accessible for an external observer (unless she/he understands and knows the language concerned), nor formally derivable from rules (unless these are available in semantic components of *grammars*), nor computable by algorithms (unless these are constrained by some form of *mental model* structures), both *reference* and *description* will be (de)constructed into components whose definition as relations appears to be too tight in view of what further specifications of them might have to cover. Therefore, the term *morphism* will be employed because it appears to capture most adequately a notion of generality needed to be expressed as a type of abstract relatedness or mapping. Unlike relations, however, which depend on the (properties of) entities that define them, *morphisms* can do without and are instead considered primal, constituting these very entities/properties in being (or becoming) related by way of such a morphism. This *morphic* type of relatedness allows for different instanciations like general mappings, relations, partial functions, functions, etc. The generality of morphisms is also preferred due to conditions whose

[42] In his *theory of fuzzy information granulation* (TFIG) ZADEH introduces *granulation* being basic to human cognition as a mode of typified generalization and representation. As an abstract type of (recursive, hierarchical, fuzzy) decomposition it serves to partition an object into a collection of granules, with a *granule* being a clump of objects (entities) drawn together by a relation that may be instantiated as indistinguishability, similarity, proximity, functionality, etc. "In this sense, the granules of the human body are the head, neck, arms, chest, etc. In turn, the granules of a head are the forehead, cheeks, nose, ears, eyes, hair, etc. In general, granulation is hierarchical [and fuzzy] in nature." [71, pp. 112]

definiteness cannot be assumed unless the need for operational applicability causes to specify them as being accessible to formal, empirical, and procedural modeling in certain settings. Devising morphisms for relational granules whose preferably set theoretical compositions can also be realized procedurally, is going to be developed in two stages each of which suggests a definitional extension in two directions.

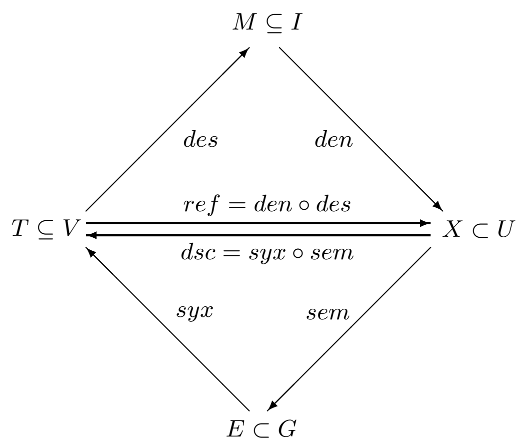

Fig. 5. Diagram representation of a (natural) language $\mathcal{L} := T \times X \to [0, 1]$ as a fuzzy relation of aggregates T of *vocabulary* items $z \in T \subseteq V$ and collections of elements $x \in X \subset U$ in the *universe* of discourse constituting the *reference* relation $ref \subseteq T \times X$ as mapping from T to X and the *description* relation $dsc \subseteq X \times T$ as its inverse $\mathcal{L}^{-1}$. Whereas the *reference* relation $ref = den \circ des$ is the composition of *denotation* and *designation* owing to the system of intensional meanings or mental models $p \in M \subseteq I$ constraining both, its inverse or the *description* relation is the composition $dsc = sem \circ syx$ of *semantic* classification and *syntactic* transformation relating (*real*) elements $x \in X \subset U$ owing to *propositionally true* and *syntactically correct* formal expressions $e \in E \subset G$ of grammar to natural language expressions $z \in T \subseteq V$.

The first level is concerned with the formal reconstruction of *reference* and *description*. As shown in the diagram of morphisms (Fig. 5), for all $z_i \in T \subseteq V$ and $x_k \in X \subset U$ by way of $p \in M \subseteq I$, as well as for all $x_k \in X \subset U$ and $z_i \in T \subseteq V$ by way of $e \in E \subseteq G$ respectively, the following compositions can be declared

- for *reference* by two intensional (conceptual) constraints: *designation* and *denotation*

$$ref := den \circ des \text{ where } \begin{cases} des \subseteq T \times M \\ den \subseteq M \times X \end{cases} \tag{5}$$

  which relate language terms $z_i \in T$ to entities $x_k \in X$ in the *real world* owing to the *concepts* or 'mental models' $p \in M \subseteq I$ whose intensions are common to both

$$den \circ des = \{(z_i, x_k) | \exists p \in M : (z_i, p) \in des \wedge (p, x_k) \in den\} \tag{6}$$

- for *description* by two extensional (grammatical) constraints: *semantics* and *syntactics*

$$dsc := syx \circ sem \text{ where } \begin{cases} sem \subseteq X \times E \\ syx \subseteq E \times T \end{cases} \tag{7}$$

which relate real world entities $x_k \in X \subset U$ to natural language expressions $z_i \in T \subseteq V$ owing to formal expressions $e \in E \subseteq G$ defining *propositionally true* and *syntactically correct* symbolic representations of the grammar G validating both

$$syx \circ sem = \{(x_k, z_i) | \exists e \in E : (x_k, e) \in sem \wedge (e, z_i) \in syx\} \tag{8}$$

The diagram (Fig. 5) can also reveal how the relatedness of different ontologies (of data material and of real world objects) may have lead cognitive psychology and cognitive linguistics to an unwarranted merge of formats for M and G creating the notion of *linguistic transparency*[43] for cognitive models which rather amounts to the opposite. Instead, the declaration of granular meaning relations and their resulting systems (of sets of fuzzy subsets) attempts to account for the ontological difference of cognitive processes underlying *description* as the intended (re)presentation of real world entities produced by NL expressions, as opposed to *understanding* as the perception of symbol aggregates and the constitution of what they convey or stand for. This distinction of processes of *meaning constitution* from those of NL *discourse generation* is based on related inter-mediate (re)presentations of not only

- intensional meanings or conceptual structures $p \in M \subseteq I$ which function like 'mental models' in mediating $T \rightarrow X$, but also
- extensional expressions of symbolic sign representations $e \in E \subset G$ which are specified by formal 'grammars' relating $X \rightarrow T$.

Their compositional cooperation constitutes (*propositionally true* and *syntactically correct*) NL language expressions T which can be understood (due to their *designating* and *denotating* intensions) to describe real world entities X.

Thus, *understanding* a language $\mathcal{L}$ introduced (Fig. 4) as a two-way meaning relation $\mathcal{M} : T \longleftrightarrow X$ (Eqn. (4)) of *reference* (Eqn. (5)) and of *description* (Eqn. (7)) has been dissolved by the intermediate representations of intensions $M \subseteq I$ and grammar $E \subseteq G$ respectively. Together with the real world entities $X \subset U$ and the NL expressions $T \subseteq V$, these allow also for the dissolution of the two-way relation $T \longleftrightarrow X$ into a cycle of mappings comprising $V \rightarrow I \rightarrow U \rightarrow G \rightarrow V$ whose (hopefully) implementable instanciations

$$\begin{array}{ll|ll} T_{t+1} = syx(E_t) & & X_t = den(M_t) \\ E_t \; = sem(X_t) & & M_t = des(T_t) \end{array}$$

and unified compositions

$$T_q = \bigcup_{t=1}^{q}\!\!\circ\; T_t \rightarrow M_t \rightarrow X_t \rightarrow E_t \rightarrow T_{t+1} \tag{9}$$

will yield dynamic changes with each processing loop t for each of the (not necessarily identical) time-scales involved $t = \{t_V, t_I, t_U, t_G\}$ to a (steady) state q.

[43] see pp.350 above

So far, this cycle only seems to corroborate what cognitive linguists have hypothesized about natural language processing, as being dependent on different types of knowledge of which *linguistic* knowledge (i.e. $E \subseteq G$ as formalized by grammars) and *real world* knowledge (i.e. $M \subseteq I$ as represented in mental models) are the most prominent. However, cast into the mould of morphisms which relate them, this re-formulation (Fig. 5 and Eqn. (9)) not only allows for the dynamism in NL understanding to be represented accordingly in a formal way. Instead, it also provides some – as yet formally specified – hints as to how, why, and by what means these knowledge bases might (have to) be augmented, complemented, or altogether substituted in the desire to translate this formal model's morphisms into empirically testable operations which parameterize relations, restrictions, functions, etc. and generate emergent representations as their result.

The second level of granular decomposition is a consequence of having refuted *linguistic transparency*[44] as an obliging exigency for cognitive modeling on phenomenological grounds. Since we have postulated different types of intermediate structures as declared above – (non propositional) intensions like $M \subseteq I$ as opposed to (linguistic) grammars like $E \subset G$ – these are in want of representational formats and/or operational specification extending the morphisms devised so far (Fig. 5). For formal grammars G, this requirement is easily met considering the numerous types of different NL grammars which have been developed, implemented, tested, and evaluated in *computational linguistics* (CL) during the last three decades. Looking for operational approaches to reconstruct intensions I satisfying similar conditions of empirical, preferably algorithmic analysis and formal representation of conceptual structures, their organization and processing, is less successful. Most of the research and development advanced by *cognitive psychology* (CP) and *cognitive linguistics* has to be discarded due to their models' lacking generality and/or limited applicability that goes with the propositional format of symbolic representations they adhere to. Therefore, the second stage in the formal reconstruction of relatedness has to somehow enable the instanciation of the two morphisms devised so far, namely *designation* and *denotation* (Eqn. (5) and Fig. 5) for which the tool of granular decomposition – as employed at the first level above – can again be applied (Fig. 6) with the advantage of ready to be used models being available for both.

The *designation* relation $des \subseteq T \times M$ is covered by a model of meaning analysis and representation in structural NL semantics. Conceived as a two-level text analyzing process recursively applied to PHT corpora as *input*, this model [44] produces a multi-resolutional representational system (of sets of fuzzy subsets) as *output* of vector formatted meaning representations in *semantic hyperspace* (SHS). It can be interpreted as the (fuzzy) intensional structure resulting from the algorithmized processing of NL texts. The underlying procedure presupposes neither prior 'world' knowledge

[44] In view of the wide spectrum that the realm of conceptual structures, mental images, and their organization presents, it is not at all convincing to assume that the organization and functioning of human minds and brains should depend on (or even be identical to) only those very categories and functions which logicians and linguists have been able to isolate from natural languages structures so far. [see pp. 350 above]

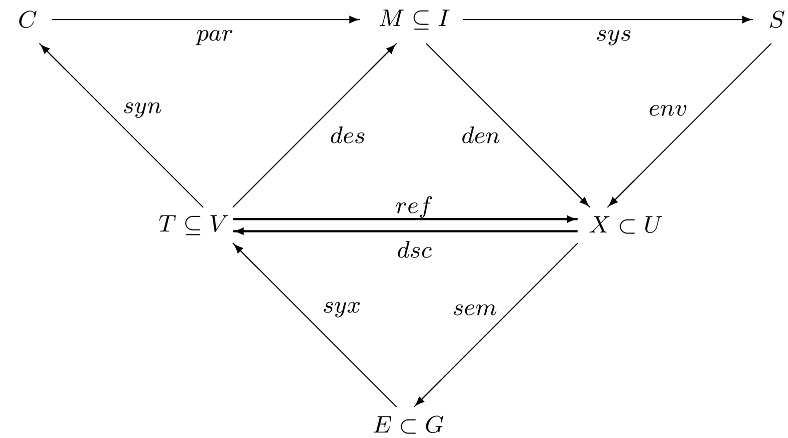

Fig. 6. Diagram of morphisms mapping vocabulary items $z \in T \subseteq V$ onto meaning points $p \in M \subseteq I$, allowing *designation* $des \subseteq V \times M$ to be reconstructed as composition $par \circ syn$. The *denotation* relation $den \subseteq M \times X$ is the composition $env \circ sys$ of the relation $sys \subseteq M \times S$ and the relation $env \subseteq S \times X$, mapping (fuzzy) intensions $p \in M \subseteq I$ to *real* situations by classifying (fuzzy) subsets X of entities $x \in X \subset U$ in the *universe of discourse* due to types of (abstracted) situational uniformities $s \in S$ common to both. Thus, the *reference* relation $ref \subseteq T \times X$ is the composition $den \circ des$, whereas its inverse *description* relation $dsc \subseteq X \times T$ is the composition $syx \circ sem$ of the relation $sem \subseteq X \times E$ relating (*real*) entities $X \subset U$ to their (*semantic*) representations $E \subset G$ of (formal) language expressions G, whose (*syntactically*) correct (natural) language strings are generated by $syx \subseteq E \times T$.

of the universe (in whatever symbolic format), nor any 'linguistic' knowledge of the syntax and semantics (as provided by whatever grammar formalism). Thus, the vector formatted representations emerging from the analyzing process of the SHS model can serve as an instanciation of the *designation* relation, i.e. of how a system (of structured sets of fuzzy subsets) of abstract but linguistically labeled entities (intensions) may be derived from language patterns automatically recognized. These are not only part of the (empirically) observable reality (situated language material) but also a condition for understandable language meanings (grounded informational contents) due to the *constraints* that semiotic processing constitutes (i.e. defines and makes use of) between different descriptive levels of linguistic structures[45] in particular.

As for the *denotation* relation $den \subseteq M \times X$, there is also a candidate available in *situation (semantics) theory* (SST) [12] which will allow to reconstruct this morphism from representations of intensions to what they may denote in the universe of discourse. Other than in more traditional theories of realistic semantics, the founding concept of *situatedness* allows to account for reality in a way which does not merely identify the formal expressions of symbolic representations with the real world entity

[45] Analogous to PATTEE's notion of *self-interpretation, self-constraint*, and *self-rule* which are at the basis of life "where the separation of genotype and phenotype through language structures took place in the most elementary form.[...] Instead of requiring simply a finite, self-*defining* system in the abstract symbolic sense, it is more fundamental to require a finite, self-*constructing* system in the physical sense. This implies a set of constraints which in some coordinated way can reconstruct themselves, as well as establish rules by which other structures can be generated. This coordinated set of constraints would amount to a language structure, that creates a new hierarchical level of organization by allowing alternative descriptions of the underlying detailed behavior." [28, pp. 253]

they are meant to stand for[46]. An ontologically more adequate treatment is achieved by intermediate levels of granular representations that distinguish *real situations* from *abstract* ones mediated by situational *uniformities* common to both. As typified by SST, real situations are no sets any more but parts of reality which provide the experiential foundations of (and hence are ontologically prior to) all subsequent abstractions that will characterize them. These abstractions are called *uniformities* represented by abstract entities like *individuals, relations, spatial/temporal locations, etc.* that tie situations together and allow for the derivation of *abstract situations* which classify *real situations* of system-environment (SE) relatedness. Although not (yet) algorithmized, SST provides the formalisms for assigning intensional representations to real world entities in the universe.

In Fig. 6 as the extended model of morphisms, both, SHS and SST serve their purpose by intermediate representations (as corpus space C and as system of situational uniformities S) that can either algorithmically be computed (like C for *des*) or generally be derived (like S for *den*) which may be introduced as follows.
For the SHS model, universal constraints of NL language structure formation known as *syntagmatics* and *paradigmatics* have been operationalized whose formal declaration as consecutive mappings is but a set theoretical composition of these two relations. As shown in the corresponding diagram of morphisms (Fig. 6), for all $z_i \in T \subseteq V$ and $p_j \in M \subseteq I$ the intermediate representation is $y \in C$ and allows to formally define the following composition

- for *designation* by two intensional (structural) constraints: *syntagmatic* and *paradigmatic*
$$des := par \circ syn \;\text{ where } \begin{cases} syn \subseteq T \times C \\ par \subseteq C \times M \end{cases} \tag{10}$$
which relate language terms $z_i \in T$ to entities $p_j \in M$ in the semantic space of *meanings* or 'mental models' owing to the intermediate representation of the corpus space $y_i \in C$ common to both.
$$par \circ syn = \{(z_i, p_j) | \exists y \in C : (z_i, y) \in syn \wedge (y, p_j) \in par\} \tag{11}$$

Analogously, the SST model allows to specify situational uniformities constraining systemic relations *sys* and environmental relations *env* which can be modeled formally by their composition. As shown in the corresponding diagram of morphisms (Fig. 6), for all $p_j \in M \subseteq I$ and $x \in X \subset U$ the corresponding representation $s_j \in S$ allows again to formally define the following composition

- for *denotation* by two extensional (situational) constraints: *systemic* and *environmental*
$$den := env \circ sys \;\text{ where } \begin{cases} sys \subseteq M \times S \\ env \subseteq S \times X \end{cases} \tag{12}$$

[46] see also p.356 (fn14)

which relate intensions in semantic space $p_j \in M \subseteq I$ to real world entities $x_k \in X \subset U$ in the universe, owing to situational uniformities $s \in S$ of abstract types of *situations* common to both

$$env \circ sys = \{(p_j, x_k) | \exists s \in S : (p_j, s) \in sys \wedge (s, x_k) \in env\} \tag{13}$$

Based upon the first cycle (Eqn. (9)), the new compositions above determine another, extended cycle comprising $V \to C \to I \to S \to U \to G \to V$ whose implementable instanciations

$$\begin{array}{l|l|l} T_{t+1} = syx(E_t) & X_t = env(S_t) & M_t = par(C_t) \\ E_t \ = sem(X_t) & S_t = sys(M_t) & C_t = syn(T_t) \end{array}$$

and unified compositions

$$T_q = \bigcup_{t=1}^{q}\!\!\circ\; T_t \to C_t \to M_t \to S_t \to X_t \to E_t \to T_{t+1} \tag{14}$$

will yield dynamic changes with each processing loop t for each of the (not necessarily identical) time-scales $t = \{t_V, t_C, t_I, t_S, t_U, t_G\}$ to a (steady) state q.

By these explicit declarations, a formal framework is laid not only for the theoretical but also for the empirical reconstruction. So-called *semiotic* procedures will have to be found that instantiate these morphisms[47] (and partial relations) to model the process of *meaning constitution* from observable language structures to result in interpretable representations of what they convey as their informational contents.

6 Empirical Reconstruction

Structural linguistics [62] has contributed substantially to how language items come about to be employed in communicative discourse the way they are. Fundamental for structural linguistics is the identification of universal[48] *constraints* underlying natural languages and their observable structures. These constraints control the multi-level combinability and formation of language entities based upon the distinction of restrictions on linear aggregation of elements (*syntagmatics*) from restrictions on their selective replacement (*paradigmatics*). It is these two-level *constraints* that fuzzy linguistics has succeeded to operationalize by devising computable procedures [45] for which algorithms have been found that instantiate them, detect and analyze language regularities, and exploit observable structures produced by the constraints concerned [55].

[47] Whether these would (have to) qualify as *semiotic morphisms* which Goguen [14] defined as level, constructor, priority, property, and structure preserving mappings $S_1 \to S_2$ of one sign systems S_1 to another sign systems S_2 is to be investigated.

[48] Syntagmatic and paradigmatic constraints are considered *universal* because apparently there is no natural language in the world known not to realize them.

> "Control constraints or mechanisms are, of course, a very complicated and ill-defined set of structures. But in essence control implies that a system possesses *alternative* behaviors, and that owing to the particular nature of the constraint it is possible to correlate a controlling input variable or signal with a particular alternative output dynamics according to a rule [or rather, regularity]. Again it is important to realize that *controls* must *operate between different descriptive levels*, just as *constraints* must be *defined by different descriptive levels*. This is necessarily the case for all [...] informational processes in which a number of alternatives on one level of description is reduced by some evaluative procedure at a higher level of description." [28, p.251, my italics]

Thus, to describe regularities by computational procedures is not only to measure varying degrees of combinatorial determinacy and to detect different patterns of the language elements' and structures' linear distributions (in texts) but also to represent their values as labeled possibility distributions. Such procedures may therefore be identified with the regularities they are able to detect as *constraints*. Being applied recursively to huge amounts of NL data in PHT corpora, the constraints structuring them will be represented as vectors in possibility spaces from which observable *syntagmata* and *paradigmata* can be computed.

6.1 Quantitative Constraint Exploration

Other than defining structures formally, either (*extensionally*) by sets of elements and relations they consist of, or (*intensionally*) as lists of those properties which the elements and relations defined comply with, the *procedural* definition[49] can be characterized as a type of operation instead of description, which may be realized by different algorithms whose actual implementations instantiate the entity defined. Whereas a procedure is (a symbolic notation of) a process abstracted from its timeliness, the instanciation of a procedure by an implemented algorithm is a process in space-time again. As such a process operates on some (input) data, its operation will produce an (output) structure which is said to be defined by that procedure i.e. defined procedurally. *Semiotic procedures* are able to identify patterns of elements in data according to inherent structural constraints, i.e. according to the elements' *syntagmatic* and *paradigmatic* relatedness which they define procedurally. As these definitions do not presuppose the type of elements to be related nor the defining relations, but depend instead on the basal structure of their input, procedural definitions are categorically soft, contextually sensitive, and open to dynamic change. These features of (level preserving and level constituting) mappings of one representational (sign) system $S_1 \rightarrow S_2$ onto another (emergent) one will also provide for the *semioticity* of the processes concerned. Their essential variability and re-constructive openness can more satisfactorily be accounted for by distributive and numerical (as opposed to symbolic and categorial) representational formats, and more easily realized in procedural models of *computational semiotics*.

[49] see also footnotes 8 and 17

Table 1. Formalization of *syntagmatic* and *paradigmatic* constraints as two-level mapping of usage regularities of items $z_i \in V$ and their differences $y_i \in C$ by consecutive (α- and δ-) abstractions resulting in meaning representations $p_i \in M \subseteq I$ respectively

$$
\begin{array}{ccccc}
 & \alpha\text{-abstraction} & & \delta\text{-abstraction} & \\
V \times V & \Downarrow & C \times C & \Downarrow & M \times M \\
\left.\begin{array}{c|c}
\alpha & z_1 \ldots z_m \\ \hline
z_1 & \alpha_{11} \ldots \alpha_{1m} \\
\vdots & \vdots \ddots \vdots \\
z_m & \alpha_{m1} \ldots \alpha_{mm}
\end{array}\right\}
& \xrightarrow{\alpha \mid z_i} &
\left\{\begin{array}{c|c}
\delta & y_1 \ldots y_m \\ \hline
y_1 & \delta_{11} \ldots \delta_{1m} \\
\vdots & \vdots \ddots \vdots \\
y_m & \delta_{m1} \ldots \delta_{mm}
\end{array}\right\}
& \xrightarrow{\delta \mid y_i} &
\left\{\begin{array}{c|c}
\zeta & p_1 \ldots p_m \\ \hline
p_1 & \zeta_{11} \ldots \zeta_{1m} \\
\vdots & \vdots \ddots \vdots \\
p_m & \zeta_{m1} \ldots \zeta_{mm}
\end{array}\right.
\\
 & \Uparrow & & \Uparrow & \\
 & \textit{Syntagmatic} & & \textit{Paradigmatic} & \\
 & & \textit{C o n s t r a i n t s} & &
\end{array}
$$

Based upon this fundamental distinction of natural language items' agglomerative or *syntagmatic* and selective or *paradigmatic* relatedness, the core of the representational formalism can be characterized as a two-level process of abstraction (Table 1). The first (called α-abstraction) on the set of *fuzzy* subsets of the vocabulary provides the word-types' usage regularities or *corpus points*, the second (called δ-abstraction) on this set of *fuzzy* subsets of corpus points provides the corresponding *meaning points* as a function of word-types which are being instantiated by word-tokens as employed in *pragmatically homogeneous* corpora of natural language texts.

The basically descriptive statistics used to grasp these fuzzy relations on the level of *words* in discourse are centered around a measure of *correlation* (Eqn. (15)) to specify intensities of co-occurring lexical items in texts, and a measure of *similarity* (or rather, dissimilarity) (Eqn. (18)) to specify these correlational value distributions' differences. Simultaneously, these measures may also be interpreted semiotically as instantiating the composition of *syn* and *par* (Eqn. (11)) as set theoretical constraints or formal mappings (Eqs. (16) and (19)) which model the meanings of words as a function of all differences of all usage regularities detected for a vocabulary as employed in a PHT corpus.

For such a corpus $K = \{k_t\}$ which consists of texts $t = 1, \ldots, T$ of overall length $L = \sum_{t=1}^{T} l_t$ with $1 \leq l_t \leq L$, measured by the number of word-tokens per text from a vocabulary $V = \{z_n\}$; $n = 1, \ldots, i, j, \ldots m$ of m word-types z_n of different identity i, j whose frequencies are denoted by $H_i = \sum_{t=1}^{T} h_{it}$; $0 \leq h_{it} \leq H_i$, the modified correlation coefficient $\alpha_{i,j}$ (Eqn. 15) allows to measure for all n word types their pairwise relatedness $(z_i, z_j) \in V \times V$ by numerical values ranging from -1 to $+1$ by calculating co-occurring frequencies of tokens in the following way

$$\alpha(z_i, z_j) = \frac{\sum_{t=1}^{T}(h_{it} - e_{it})(h_{jt} - e_{jt})}{\left(\sum_{t=1}^{T}(h_{it} - e_{it})^2 \sum_{t=1}^{T}(h_{jt} - e_{jt})^2\right)^{\frac{1}{2}}}; \ -1 \leq \alpha_{ij} \leq +1 \tag{15}$$

$$\text{where } e_{it} = \frac{H_i}{L} l_t \ \text{ and } e_{jt} = \frac{H_j}{L} l_t$$

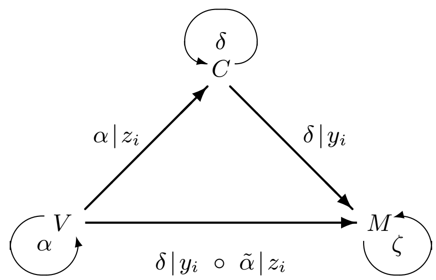

Fig. 7. Fuzzy mapping relations α and δ between the structured sets of vocabulary items $z_i \in V$, of corpus points $y_i \in C$, and of meaning points $p_i \in M$.

Evidently, pairs of items which frequently either co-occur in, or are both absent from, a number of texts will positively be correlated and hence called *affined*, those of which only one (and not the other) frequently occurs in a number of texts will negatively be correlated and hence called *repugnant*.

As a fuzzy binary relation, $\alpha : V \times V \rightarrow \Im_\alpha$ can be conditioned on any $z_n \in V$ which yields a crisp mapping as operational definition of the *syn* relation

$$\alpha \mid z_n : V \rightarrow C. \tag{16}$$

C is the set $\{y_n\}$ defined by the tuples $\langle((z_n, z_1), \alpha(n,1)),\ \ldots,\ ((z_n, z_m), \alpha(n,m))\rangle$ representing the numerically specified, *syntagmatic* usage regularities that have been observed for any word-type z_i against all other $z_n \in V$ as measured by α-values. The so-called *α-abstraction* over the first of the components of each ordered pair (z_i, z_n) determines these usage regularities' abstract representation y_i as points in the the m-dimensional *corpus space* C

$$z_i(\alpha(i,1), \ldots, \alpha(i,m)) := y_i \in C \tag{17}$$

As shown in Table 1, the regularities of usages of each lexical item can numerically be expressed by the α-tuples of *affinity/repugnancy*-values measured against any other item of the vocabulary $V \times V$ as employed in the text corpus analyzed. By α-abstraction each m-tuple of α-values (rows) defines an element – the so-called *corpus point* – $y_i \in C$ in the system C (the set of fuzzy subsets of the vocabulary) represented as vectors in the *corpus space* which is spanned by the number m of axes each corresponding to one vocabulary entry.

6.2 Distributed Meaning Representation

Considering the *corpus space* a representational structure of abstract entities (*corpus points*) which are constituted by measurement of *syntagmatic* regularities of word-token occurrences in discourse, then the similarities and/or dissimilarities of these entities will capture their corresponding word-types' *paradigmatic* regularities. These may be calculated by a distance measure δ of, say, Euclidian metric $\delta : C \times C \to \mathbb{R}$ which also makes C a metric space $\langle C, \delta \rangle$ with

$$\delta(y_i, y_j) = \left(\sum_{n=1}^{m} (\alpha(z_i, z_n) - \alpha(z_j, z_n))^2 \right)^{\frac{1}{2}} ; \qquad (18)$$
$$0 \leq \delta(y_i, y_j) \leq 2\sqrt{m}$$

Thus, δ serves as a *second* mapping function to represent each item's differences of usage regularities measured against the usage regularities of all other items. As a fuzzy binary relation, $\delta : C \times C \to \Im_\delta$ can be conditioned on $y_n \in C$ which again yields a crisp mapping as operational definition of the *par* relation

$$\delta \mid y_n : C \to M; \{p_n\} =: M \qquad (19)$$

where the tuple $\langle (y_{i1}, \delta(i,1)), \ldots, (y_{im}, \delta(i,m)) \rangle$ represents the numerically specified *paradigmatic* structure that has been derived from the system of *syntagmatic* usage regularities y_i against all other $y_n \in C$. These δ-tuples of distance values can therefore – in analogy to Eqn. (17) – again be abstracted, this time however, over the second components in each of the ordered pairs, thus defining new elements $p_n \in M$ called intensional *meaning points* by

$$y_n(\delta(n,1), \ldots, \delta(n,m)) =: p_n \in M \qquad (20)$$

And as shown in Tab. 1, the differences of usage regularities of lexical items $C \times C$ are calculated and numerically expressed by δ-values whose *similarity/dissimilarity* form the base of δ-abstraction. The resulting δ-tuples of each one corpus point measured against all the others in the system (*corpus space*) define and identify new abstract entities in a new system, i.e. *meaning points* $p_n \in M$. After introducing a Euclidian metric $\zeta : M \times M \to \mathbb{R}$, its labeled elements may again be measured to specify fuzzy subsets of potential paradigms which can structurally be constrained and evaluated without (direct or indirect) recourse to any pre-existent external world. By

$$\zeta(p_i, p_j) = \left(\sum_{n=1}^{m} (\delta(y_i, y_n) - \delta(y_j, y_n))^2 \right)^{\frac{1}{2}} ; \qquad (21)$$
$$0 \leq \zeta(p_i, p_j) \leq 2m$$

the hyper structure $\langle M, \zeta \rangle$ or *semantic hyper space* (SHS) can be computed constituting the system of intensional *meaning points* $p_n \in \langle M, \zeta \rangle \subseteq I$ as an empirically founded and compositionally derived lexically labeled representation of intensions. It is to be noted that this empirical reconstruction of intensional meanings as lexicalized in a language and constituted by performative discourse is a (partial) function of differences of usage regularities as constrained by a two-level process of restrictions on the linear (*syn* = syntagmatic) and selective (*par* = paradigmatic) combinability of words.

Essentially, these new representational structures are value distributions or vectors of input entities that depict properties of their structural relatedness, constituting multi-dimensional systems and (metric) space structures (*semiotic spaces*). Their elements may be interpreted in a variety of ways as (labeled) *fuzzy sets* allowing set theoretical and numerical operations be exercised on these representations that do not require categorial type (*crisp*) definitions of concept formations, or as entities (points) in space structures allowing topological interpretations and the procedural definition of new (dynamic) organizations generated by algorithms which operate on such spaces and reorganize their structure in dependency graphs [49] according to any chosen point's perspective [57].

6.3 Systemic Situational Grounding

Having suggested *situation (semantics) theory* (SST) as a possible frame for grounding systems in their environment by way of their *situatedness* (see above p. 378), the *denotation* relation $den \subseteq M \times X$ (Eqn. (12)) can be reconstructed as $den = env \circ sys$ (Eqn. 13) by way of uniformities of abstract situations $s \in S$. This is achieved by intermediate levels of granular representations that allow to distinguish *real situations* from *abstract* ones mediated by situational *uniformities* common to both, systemic intensions $p \in M \subseteq I$ and entities of the universe $x \in X \subset U$. As typified by SST, real situations are no sets any more but parts of real system-environment (SE) relations which provide the experiential foundations of (and hence are ontologically prior to) all subsequent abstractions that will characterize them. These abstractions – as mentioned before – are called *uniformities* like *individuals, relations, spatio-temporal locations, etc.* that tie situations together and allow for the derivation of *abstract situations*. Although not (yet) algorithmized, these provide access also to a situational grounding of systems in their environment.

To give an idea of how this grounding (see p. 355) is assumed to be modeled for the reconstructive purpose at hand, lets think of the phenomenon of *dynamics* observable in the real world or the *universe* as a function of *spatiality* and *temporality*. Although these concepts are indistinguishable at the genotypical source, they ought to be realized as discriminating both *systems* from *environments* by extending into higher complexities. In Fig. 8 this source point is marked by a circle from which the concept types of *spatiality*, *temporality*, and their mutual composite *dynamics* extend to (a plane of) their increasing distinguishability (vectorially illustrated by arrows), as do the concepts of *system* and its *environment* (orthogonal to that plane) determining the spaces above and below (that plane) which are conditional for the notion of dynamics and its observable (operational, measurable, etc.) accessibility.

For terminological clarity, the scaling of the spatial, temporal, and dynamic arrows extending from the source point can – tentatively as in Fig. 8 – be instantiated by concepts whose parameterizations differ – not only by name – for the *system* area (above the plane) and the *environment* area (below the plane), allowing to capture the duality which is the only view that realistic epistemology provide. Thus, *dynamics* translates for systems to their *mobility* which may be characterized by *pace* step

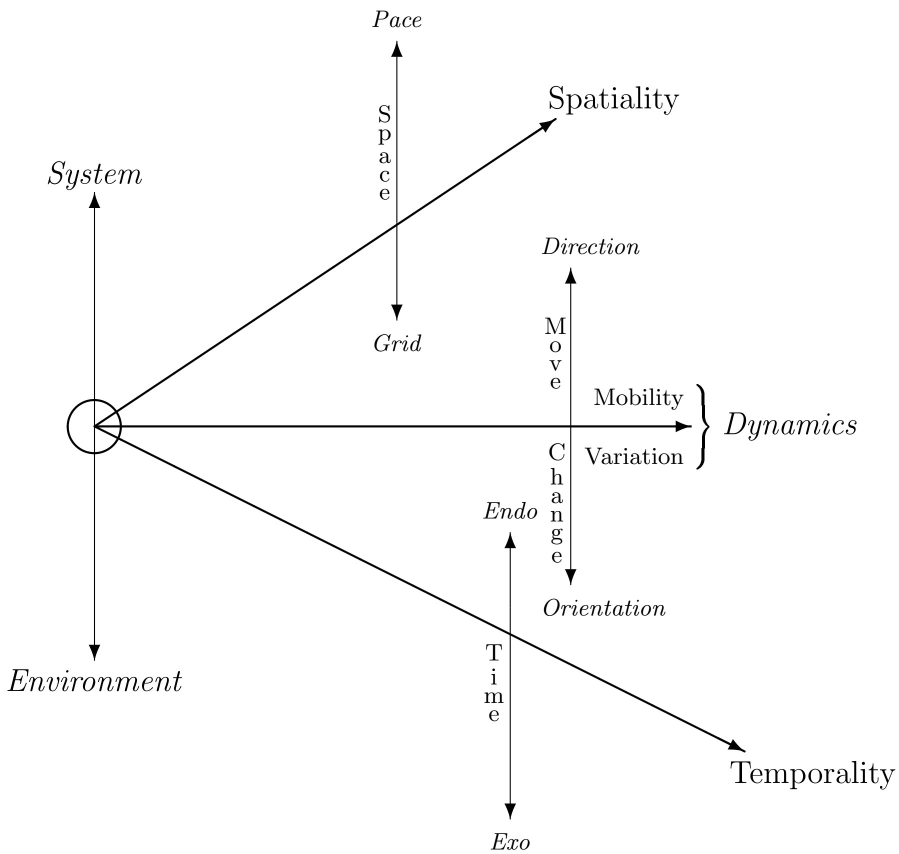

Fig. 8. Situational uniformities as an **abstract** composite relation of *spatiality* and *temporality* constituting the *dynamics* of the system-environment coupling. In order to render this dynamics conceptually accessible, systemic *mobility* and environmental *variation* have to be **actual** in order to be instantiated as *pace/grid* scaling and *endo/exo* time cycles, whose parameterized ratios allow *directional moves* of systems and/or *oriented changes* of environments become **factual** (measurable) due to their situational uniformities.

per *endo*-time cycle ratio, whereas for environments the *dynamics* amounts to their *variation* measured by *grid* number per *exo*-time cycle ratio[50]. Satisfying certain conditions of monotonicity, a system's mobility may further be specified by the *direction* of its moves, and the environmental variation by the *orientation* of its changes[51]. To characterize the system-environment relatedness of situated cognitive processes, instanciations of types of parameters like *pace/grid*, *direction/orientation*, *endo/exo*-time – and many more that might be specified for different situations of arbitrary complexity – not only have to be identified but also are to be determined in how they couple systems and environments structurally to each other.

[50] Assuming a synchronized *endo/exo*-time and a stable (steady-state) environment, mobility may be specified simply by the pace step per grid number ratio.

[51] As Fig. 8 suggests, *system* and *environment* need not be as far apart but may even be indistinguishable from each other, conflating in the source point (circle) with no spatial extension or timely duration. Such an identity would reduce the categorial framework of *spatiality* and *temporality* as well as space-time *dynamics* to the traditional, non-situational form of characterizing real world phenomena as externally determined and independent from an observer in a naive positivist stance.

For SCIP system-environments (as specified for experimental test purposes in Tables 3 and 4 below), this coupling can be determined by the isomorphism of system *directions* and environment *orientations* $\mathcal{D} = \mathcal{O}$, and the correspondence of *pace* and *grid* as a function $f(\mathcal{P}/\mathcal{G})$, whereas – for reasons of simplicity – temporal coupling was neglected altogether as a modeling parameter. Hence, mobility is modeled as the system's moving about at a pace-grid ratio k/g from system position $SP_{\mathcal{P}}$ to system position $SP_{\mathcal{P}} + 1$ for all $R(n_0, m_0) \in \mathcal{R}_P$ in the *reference plane* where (fixed) object locations $OL_R(n, m)$ mark those grid points that cannot be taken or moved to by the system. Thus, relations of system positions and object locations (SPOL-relations) are what couples the cognitive system with its environment. This SE relation, however, is not experienced directly by the system as measured by changing coordinate values for its moving positions in the universe, but rather mediated by natural language descriptions of that relation whose situational processing constitutes (understanding of) its meaning and serves as – what might be called – a *semiotic* or SCIP coupling.

Table 2. Collection of defining constraints that determine language material entities constituting the SCIP coupling of system and environment.

SCIP **Coupling**:
Word: the entity (sign) identified as vocabulary element (type) whose occurrences (tokens) in (linear) sets of entities 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 *SPOL* relations resulting from the system's linear movement to directly adjacent positions;
Corpus: the (non-empty) set of texts comprising descriptions of (any or all) factually possible *SPOL* relations within a specified systemic and environmental setting.

This rather rough approximation of very simple situational uniformities which would likely be identified to determine equally simple relations of cognitive systems within their environments, is to illustrate which minimal requirements a SCIP situation of system-environment relatedness will have to satisfy. In order to let intensional representations $p \in M \subseteq I$ from processing NL discourse be assigned to real world entities $x \in X \subset U$ in the universe, these requirements, or rather some (gradual) satisfaction of them, ground that system by way of its understanding of meanings mediated or described by the textual structures in the discourse processed. In fact, presupposing the informational meaningfulness of discourse (instead of the existence of the real world as *environment* and the cognitive mind/brain as *system*) will render PHT corpora to become representations of semiotic SE situations.

Processing of such corpora will establish a particular, i.e. *semiotic* kind of structural coupling between system and environment, such that – due to their situational uniformities – the informational content of language discourse is structurally conveyed as overall meaning of the PHT corpus, very different indeed from the propositional information of strings of declarative sentences. From the structural processing point-of-view which the system is capable to perform, the language material assembled in the PHT *corpus* consists of structural patterns of *words, sentences*, and *texts* as characterized in Table 2. These have to and can be specified in a variety of different ways (as e.g. here by a formal *grammar* with *syntax* and *semantics*) which – and this is the crucial point – are unknown to the SCIP system and also well beyond its capabilities to process.

7 Understanding Language Understanding

Processing SCIP coupled natural language PHT corpora the way which the morphisms (Fig. 6) and their instanciations indicate, would appear to grasp some relevant portions of the ability of language *understanding*. Whenever a system – processing language regularities in $z \in T \subseteq V$ that are external to it – comes up with an internal representation of structure $p \in P \subseteq M$ which specifies the informational contents of what the corpus processed describes of the real world facts $x \in X \subset U$, then the system has enacted some *learning*. 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* by the computations the procedural model specifies. This is what the first cycle of morphisms (Fig. 5 and Eqn. (9)) and the processing of the SCIP system's situational setting (Fig. 3) are to illustrate in a formal and a schematic way. And this is also what the second cycle of morphisms (Fig. 6 and Eqn. (14)) has been devised to determine formally in Table 1.

The problem that has to be addressed now is, whether (and if so, how) the contents of what such a system is said to have acquired or understood (processing PHT corpora) can be tested, i.e. made accessible for scrutiny other than by understanding these very texts, and without committing to a particular semantics whose presuppositions would inevitably determine all possible interpretations. What we have at our disposal so far, is a system of word meanings (*lexical knowledge*) which has been modeled in a vector space format $\langle M, \zeta \rangle$ as a relational data structure whose linguistically labeled elements (*meaning points*) and their mutual distances (*meaning differences*) form a system of potential *stereotypes*[52]. 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) in that system which interprets the lexical label attached to it, not vice versa [43,49]. 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*.

[52] 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 computed from quantitative text analyses.

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 an artificial multi-level conceptual knowledge representation system [44]. 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) constituting the attuned system's *adaptation*, and its long-term *structure* as the addressable representation of knowledge (stereotype or concept) which is a form of *learning*[53]. From a semiotic point-of-view both are necessary components of *understanding* with the 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 structures[54] whose dynamics and efficient (re)organization is part of *understanding* and can thus only be modeled procedurally.

As we have introduced the process-result perspective on cognition to allow the mind-matter or endo-exo distinction become a result of cognitive processing rather than its presupposition, what appears to be disturbing on first sight is that the procedural models of cognitive processes – not the processes themselves – produce accessible results by their 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, a n d simultaneously 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[55]. However, on second thought the computational semiotician finds herself/himself engaged in a constitutive part of the very process of learning to understand or in constituting meaning (as a semiotic function) which she/he was trying to model as a process of knowledge-based information processing (as a 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 – as defined a n d structured by the computational processes of textual analyses described above – might be involved in mediating or constituting that duality, an experimental setting has been designed. It is based on the assumption that a type of core structure – similar to that one modeled by SHS – ought to be postulated. This core could be considered a common base for different notions of meaning or content of natural language expressions developed by

[53] see also pp. 358 and footnote 41 above.

[54] 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.

[55] It appears that what Pattee [31] 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.

theories of *referential* and *situational* semantics as well as some theories of *structural* or *stereotype* meanings. Therefore, real world situations with directly and externally observable space-time parameters, however restricted, are to be preferred over any conceivable symbolic representation of such situations whose encoding might introduce unwarranted abstractions and/or simplifications.

7.1 Experimental Testing

For the purpose of testing *semiotic* processes of *learning* as meaning constitution or *understanding* against the purported *semantic* contents of natural language *descriptions* of reality, situational complexities have to be reduced by abstracting away irrelevant components, hopefully without oversimplifying the issue and trivializing the problem. Hence, the propositional form of natural language predication – undoubtedly the common basis of traditional meaning theories – will not be done away with or neglected. Instead, a sentence generating text grammar and a formal semantics shall be employed to construct and generate in a controlled way the meaningful contents of the natural language material which is to be used for the training and testing of the system, not however, will the propositional structure determine the way this training material is to be processed during the test.

Given a two-dimensional real-world scenario with a mobile system moving about in between object obstacles, semantically well defined and truth conditionally clear language expressions of propositions denoting referentially doubtless facts in specified situations of such a scenario, would appear to be a necessary condition for a test. It will have to reveal whether or not a non-propositional processing of strings of propositions in a PHT corpus can result in some structure which is either similar, or even identical, to the facts described by these texts, or whether this structure can at least be related in some regular way to the structures these texts refer to. Therefore, the SCIP system's language understanding process (as formally specified by Fig. 5 and schematically illustrated in Fig. 3) is supplemented – as shown in Fig. 9 – by the text generating modules (*referential semantics* and *propositional grammar*) to produce the input (*natural language discourse*) in a controlled and well defined way. The processing of that input leading to the internal representation (*semantic space structure*) is augmented by structure detecting modules (*agglomerative clustering* and *visualizing transformation*) which will allow for a pictorial representation of the semantic space structure as computed from the text corpus describing the real world situations. Comparing – as illustrated by the left and right frame in Fig. 10 – the image of the (external view of) environment with the visualization of the (internal view of) meaning as constituted from the texts processed describing that environment as their contents, would seem to be a feasible approach to test *language understanding* as enactive *learning*.

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

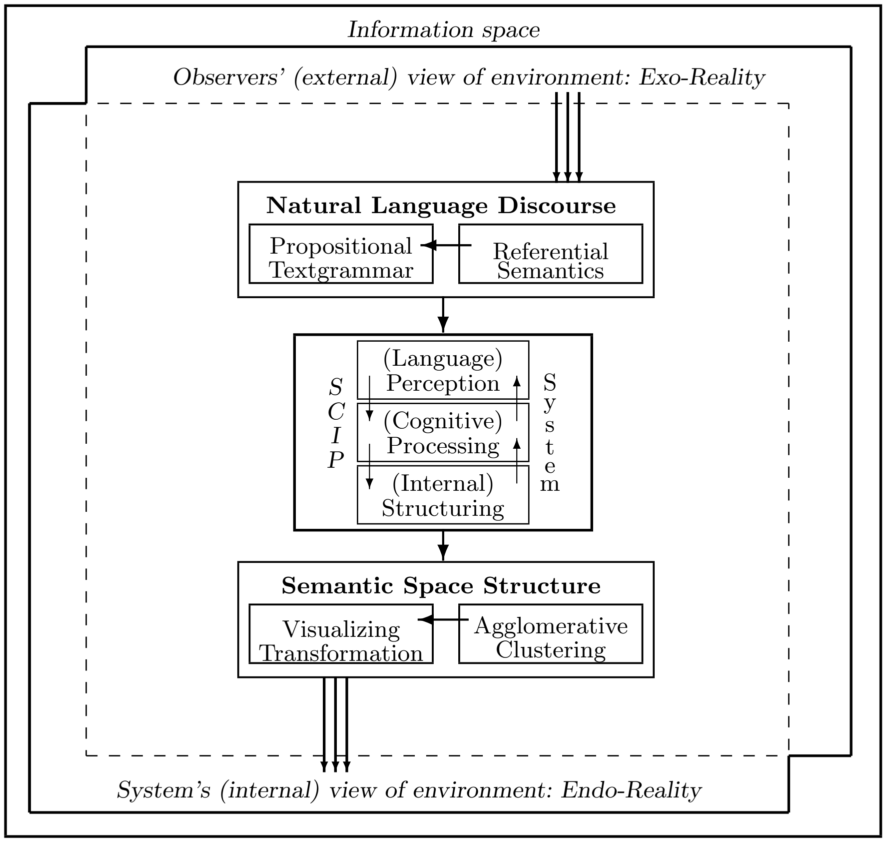

Fig. 9. Situated test cycle to compare the (enigmatic) endo-view resulting from the modeled SCIP system's (well-known) processing against the (well known) exo-view that traditional CL models of syntax and semantics offer to clarify the (enigmatic) processes underlying natural language understanding. Referential semantics and propositional text-grammar allow to generate PHT corpora of true NL descriptions of (real world) SPOL relations. Their non-symbolic, two-level processing results in the SCIP system's semantic hyperspace SHS-structure. Visualizing its clustering structures allows for a comparison of results which computational models of subsymbolic processing yields against what grammatically correct and semantically true propositions encode as meaning or informational content.

objects at certain places which are to be identified[56]. The system's channels of perception allowing to form its 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 a software 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, i.e. natural language texts, a n d to (re)present the results

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

in some dynamic structure which determines the system's knowledge (susceptibility), learning (change) and understanding (representation).

The experimental setting developed to allow for testing language understanding against the reality described 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 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 other accepted, well defined model of cognitive (language) understanding. And test results would have to be considered (partially) positive for all cases in which the contents of the same language expressions is represented or depicted in 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 tested against and compared to the (well known) interpretative *results* which linguistics proper and computational linguistics traditionally agree to propose for the (unknown) *processes* of natural language meaning constitution[57]. Accordingly, 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 in modeling *learning* and language *understanding*.

7.2 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

[57] 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, theoretical, inter-subjective) *models* to deal with, whereas "*unknown*" refers to the lack of such models.

Table 3. Collection of SCIP systems' formal properties. Note, that there is neither syntactical, nor semantic knowledge defined to be provided for the system. Mobility, direction, and endo-time are instanciations of *mobility uniformities* guaranteeing systems' identities.

SCIP **System** :	$\{\mathcal{L}, \mathcal{C}, \mathcal{D}, \mathcal{P}, \mathcal{T}_S\}$
Lang. Perception :	$\mathcal{L} := \{K := \{k_t\}, L := \sum_{t=1}^{T} l_t, V := \{x_i\}, H_i := \sum_{t=1}^{T} h_{it} : i = 1, \ldots, j, \ldots, N\}$
Cogn. Processing :	$\mathcal{C} := \{\alpha,\ \delta,\ \zeta,\ \ldots\};\ \{\tilde{\alpha} \mid x,\ \tilde{\delta} \mid y,\ \ldots\}$
Semantics :	**none**
Syntax :	**none**
Direction :	$\mathcal{D} := \{\boldsymbol{N} = (0,1), \boldsymbol{E} = (1,0), \boldsymbol{S} = (0,-1), \boldsymbol{W} = (-1,0)\}$
Pace :	$\mathcal{P} := \{k(0,1), k(1,1), k(1,0), k(1,-1), k(0,-1), k(-1,-1), k(-1,0), k(-1,1) :\ k = 1\}$
Endotime :	$\mathcal{T}_S := t_1, \ldots, t_S$

Table 4. Collection of SCIP environments' formal properties. Orientation, grid measure, and exo-time are instanciations of observational *uniformities of change* guaranteeing environments' identities.

SCIP **Environment** :	$\{\mathcal{R}_{\mathrm{O}}, \mathcal{R}_{\mathrm{P}}, \mathcal{O}, \mathcal{G}, \mathcal{T}_E\}$
Reference objects :	$\mathcal{R}_{\mathrm{O}} := \{\square,\ \triangle,\ \ldots\}$
Reference plane :	$\mathcal{R}_{\mathrm{P}} := \{P_{n,m} : \exists R_{n,m} \in R(n_0, m_0, g), P_{n,m} \in R_{n,m}\}$
Orientation :	$\mathcal{O} := \{\boldsymbol{N} = (0,1), \boldsymbol{O} = (1,0), \boldsymbol{S} = (0,-1), \boldsymbol{W} = (-1,0)\}$
Grid :	$\mathcal{G} := R(n_0, m_0, g) = \{R_{n,m} = [(n-1)g, ng] \times [(m-1)g, mg], 1 \le n \le n_0, 1 \le m \le m_0, g > 0\}$
Exotime :	$\mathcal{T}_E := t_1, \ldots, t_E$

Table 5. Syntax of text grammar for the generation of strings of correct descriptions of possible SPOL (system-position and object-location) relations.

T(ext) :=	$\{S_i \mid S_i \longrightarrow S_{i+1} : \mathcal{B} \wedge \{KP_1, KP_2\} \in S_i \wedge \{KP_1, KP_2\} \in S_{i+1} \wedge \forall\ KP_j \in S_i \cup S_{i+1}; j = 1, 2;\quad i = 1, \ldots, I\}$
$\mathcal{B}$:=	$\{k(0,1), k(1,1), k(1,0), k(1,-1), k(0,-1), k(-1,-1), k(-1,0), k(-1,1) :\ k = 1\}$
$S_i \longrightarrow$	NP VP
NP $\longrightarrow$	N
VP $\longrightarrow$	V PP
PP $\longrightarrow$	HP KP
N $\longrightarrow$	*a* ⟨ *triangle* | *square* ⟩
V $\longrightarrow$	*lies*
HP $\longrightarrow$	⟨ *extremely* | *very* | *rather* ⟩⟨ *near* | *far* ⟩
KP $\longrightarrow$	⟨ *on the left* | *on the right* ⟩ | ⟨ *in front* | *behind* ⟩

or trivialize the problem. Trying to achieve this, SE relational parameters have to be determined guaranteeing that the three main components of the SCIP experimental setting, the *system*, the *environment*, and their coupling by means of *discourse* are specified by sets of conditioning properties:

- The SCIP system is determined as a set of (partly procedural) performance parameters (Table 3) like *language perception* $\mathcal{L}$ and *cognitive processing* $\mathcal{C}$, complying with the *syn* and *par* components of the *designation* morphism *des* (Fig. 6) defined by Eqs. (10) and (11), as well as the system's mobility parameters *direction* and

Table 6. 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).

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 SPOL (*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

pace, instantiating the systemic component *sys* of the *denotation* morphism *den* (Fig. 6) and complying with the systemic part of Eqs. (12) and (13).

- The SCIP environment is defined as a set of formal entities like *reference objects* and *reference plane* as well as *orientation* and *grid* (Table 4), instantiating the environmental component *env* of the *denotation* morphism *den* (Fig. 6) and complying with the environment's part of Eqs. (12) and (13).
- The SCIP discourse material which structurally couples system and environment (SCIP *coupling*) is defined as a PHT corpus (Table 2) of which *sentence* and *text* require further definitional restrictions. These are provided by a formal *syntax* (Table 5) and referential *semantics* (Table 6).

Thus, the system's environmental data is provided by a corpus of (natural language) texts comprising correct expressions of true propositions denoting how system-positions (SP) relate to object-locations (OL), called SPOL relations for short. As externally observable material world relations, these may be described according to the formally specified syntax and semantics (representing the *exo*-view or *described situations*), so that the system's internal picture of its surroundings (representing the *endo*-view or *discourse situations*) may be derived from this language environment other than by way of propositional reconstruction, i.e. perception based and without any syntactic parsing and semantic interpretation of sentence and text structures.

In this way, the *exo*-knowledge which the experiment's designer has to control for the *propositional* encoding and decoding of information in texts that the SCIP system will be exposed to, can indeed be kept strictly apart from the system's *endo*-

capacities of text processing which by definition do not include this knowledge. Thus, the system's own *non-propositional* processing will allow for some results as the system's *internal* representations which would not be interpretable as mere repetitious reproductions or as an application of knowledge structures made available to it *externally*. Instead, these *endo*-results would have in principle a chance to be different from – though hopefully 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.

7.3 Processes and Results

The example lay-out is illustrated by the location of the two objects *triangle* and *square* and the mobile *system* in the reference plane (Fig. 10 left part). These provide the base for the cognitive situations which consist in all possible system-*positions* (SP) for each of the *directions* $\mathcal{D}$ relative to the two object-*locations* (OL). The language expressions describing these SPOL relations were generated automatically for the given OL and all possible SP according to the formal syntax (Table 5) and semantics (Table 6) specified. The generated PHT corpus of descriptions provides the training material which the SCIP system is exposed to for processing. Perceived as environmental data solely available, it is processed according to the specified faculties (Table 3), namely *language perception* $\mathcal{L}$ and *cognitive processing* $\mathcal{C}$, i.e. identifying, counting, computing, and abstracting string entities of different (and emergent) types as introduced and specified by Eqs. (15–20) above. Although perception is limited to the formal (language) processing capabilities specified (which do not entail any knowledge of syntax and semantics), and as the ability to act (and react) is restricted to the system's stepwise linear movement, SCIP will come up with some internally represented structure as processing result whose visualized image (Fig. 10 right part) corresponds vaguely to the described external environment (Fig. 10 left part) allowing for direct comparison.

In the course of this visualization process – outlined in some detail elsewhere [57, pp.157–193] and only summarized here – the composite morphisms (Fig. 7) as modeled in the two-level mapping of emergent abstractions (Table 1) result in $\langle M, \zeta \rangle$ or the *semantic hyper space* (SHS) whose intrinsic structuredness can be exploited in a three stage process:

- first, applying methods of average linkage cluster analysis allows to identify structurally similar word type adjacencies (like entity labels of object and predicate candidates) [54] which results in an internal, highly resolutional organization comparable to that of self-organizing semantic maps [19] [61] which are less structured;
- second, transforming the *numerical* hedge interpretation of the SPOL distance values whose *directional* core interpretations determine virtual regions of object locations relative to the system's central position from an intermediate layered

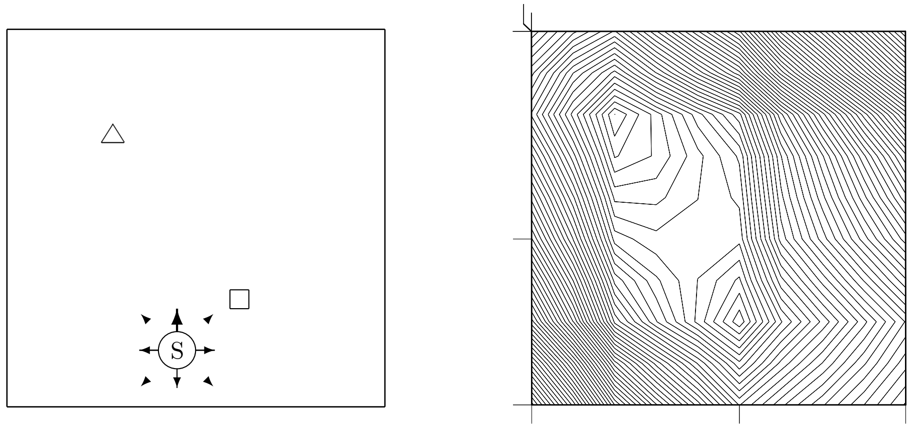

Fig. 10. External view of reference plane with mobile system S and location of objects △ and □ (*Exo-Reality*) propositionally described as SPOL relations (*e.g. "Square is extremely near in front, extremely near to the right"*) in texts forming the training corpus (*structural coupling*), and 2-dim-image of *SCIP* system's view of its environment (*Endo-Reality*) showing regions of potential object locations by profile lines of common likelihood (*isoreferentials*).

data matrix $Endo1_{i,j}$ to result in a summation matrix $Endo2_{m,n}$ according to

$$Endo2_{m,n} = \sum_{i=m}^{m+q} \sum_{j=n}^{n+q} Endo1_{i,j} \tag{22}$$

where q is a variable that takes values of maximum g (grid points), and

- third, visualizing this data in some other format as a holistic representation (image) comparable to the referential plane $\mathcal{R}_P$ now structured by a pattern of polygons which connect regions of equivalent denotational likelihood – called *iso-referentials* – of possible object-locations in a two-dimensional format (Fig. 10 right part).

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 as illustrated by its 3-dimensional profile (Fig. 11). 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 frame for representing definite locations by abstracting from their situational embedding.

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 factual situation of varying system positions relative to fixed object locations (SPOL-dynamics) of which – in all of its instances – the language material gives a

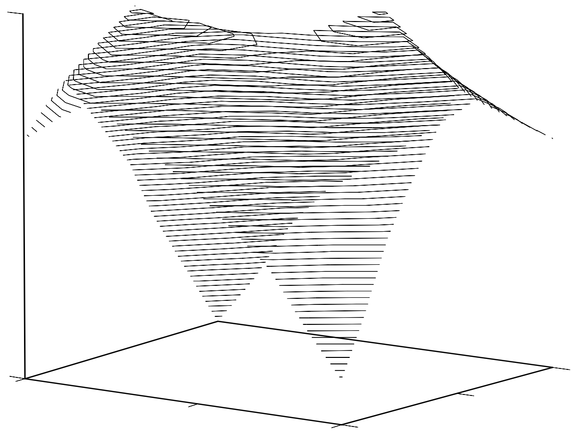

Fig. 11. *3-dim*-profile of the SCIP system's *endo*-view of its *environment* showing highest potentials for likely object locations (OL) under *crisp* hedge interpretation, as computed from the training corpus of texts describing these locations relative to system positions (SP) in the reference plane.

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. The non-propositional processing of a set (*corpus*) of sets (*texts*) of correct language expressions (*sentences*) of true meanings (*propositions*) describing (fixed) object locations relative to (varying) system positions resulted in a (dynamic) topology of labeled meaning points. Being in a vector space format (SHS), its intrinsic structure was made visible by three consecutive stages of representations. These visualizations were based on the $crisp_{1.0}$ interpretations of the hedges. Using instead the $fuzzy_{1.1}$ definitions (Table 6) to interpret the adjacencies of hedged core predicate labels has produced comparable images due to even more distinctive structures emerging from the data as outlined elsewhere [57, pp.192].

It is worthwhile noting here again, that the SCIP system's processing is neither based on, nor does it involve any knowledge of *syntax* or *semantics* on the system's side (Table 3). Thus, the SHS structure appears to emerge from the system's NL text processing and representation procedures which realize *learning* as a procedural model of *meaning constitution* and *knowledge acquisition* enacted as (a sort of) perception based *language understanding* by machine.

8 Conclusion

Because semiotic *structures* (signs) have space-time extension and are in principle observable apart from and independent of being processed cognitively, the *processes* operating on and modifying them can be modeled – as outlined before – independent of their temporal duration by *procedures*. Their formal notations as executable programs 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 the emergent *structures* which are in fact – not only in principle – observable. This two-sided independence facilitates procedural models to relate structured *language expressions* which can be observed and analyzed without being understood, to *language understanding* processes which can be abstracted from their temporal duration and thus conceived as procedures. It appears, that by this move procedures and algorithms found to model some aspects of semiotic cognitive information processing for language understanding can be tested against – not on the grounds of – other well established or accepted models of cognitive (language) comprehension[58].

As an object for the modeling enterprise, NL understanding is ambiguous: it applies likewise to the *processes* concerned as well as to their *results* whose mutual dependency has to be accounted for by models claiming to be adequate. Clarifying the process/result ambiguity is to *analyze* and to *specify*: analyze in order to find the type of *structures* underlying the *results*, and specify in order to determine the class of *processes* which will produce these *results*, before *procedures* can be devised whose implemented *instanciations* may qualify as realizing these *processes* which will operate on and, in turn, modify (old) and generate (new) *structures* as the *results* of NL understanding.

1. Modeling *semiotic cognitive information processing* (SCIP) systems' performances, the concept of *representation* is considered fundamental. To realize – instead of simulating – the experiential distinction of semiotic *processes* (of cognition) from their *results* (as representational structures) is – due to the traces these processes leave behind – a process of emergence of discernible forms of (interpreted) structures as *acquisition* of *knowledge*. Computational semiotics embarks on the venture to (re-)construct algorithmically these emergent structures from natural language discourse which lie at the base of cognitive processes and are representational for them.
2. Dealing with natural language structures, *computational semiotic* approaches are able to (re)present a term's functional potential by a (fuzzy) *distributional pattern* of the modeled SCIP system's state changes – rather than by a *single symbol*. Its structural relations serve to depict the system's possible interpretations of that symbol in its environmental setting. Whereas symbolic representations have to *exclude*, the distributional representations will automatically *include* the contextual

[58] A SCIP system-environment setting – which will shortly be accessible also via internet [59] – was developed to allow for the experimental testing of varying *results* of language understanding against changing *processes* of SPOL relations described. The test design hinges on the idea that SCIP will have to operate on and produce the structures which are a condition for and a results of such processing.

sensitivity of (linguistically represented) pragmatic components. A SCIP system's representational and procedural import will both, embody and employ these components to identify and to interpret its environment due to, and by means of its own structuredness (SCIP coupling).

3. In *fuzzy linguistics*, lexical semantics is concerned with (re-)constructing language entities' *semiotic* potential (meaning function) by weighted graphs (fuzzy *distributional patterns*) which represent the modeled system's state space rather than isolated semantic descriptions tied to singular *symbol aggregates* whose interpretation has to be arbitrary. In this view the emergence of semantic structure can be represented and studied as a self-organizing process of *learning* based upon word usage regularities in natural language discourse.
4. The *semantic hyperspace* (SHS) may also be interpreted as an internal (*endo*) representation of the SCIP system's acquired knowledge of, or its informational states of adaptation to the external (*exo*) structures of its environment. The degree of correspondence between these two is a function of *granularity* as determined by the resolution that the texts provide in depicting an *exo*-view, and by the structuredness that the SCIP system is able to acquire as its *endo*-view in the course of processing these texts as medium.
5. The *dynamics* of semiotic (knowledge) structures and the processes operating on them essentially employ recursively applied mappings of multilevel representations resulting in a multi-resolutional granularity of fuzzy word meanings which emerge from and are modified by such natural language processing. Test results from experimental settings (in semantically different discourse environments) are produced to illustrate the SCIP system's granular language understanding and meaning acquisition capacity without any initial explicit morphological, lexical, syntactic, or semantic knowledge.
6. Analyzing the *complexities* of natural language discourse in the aggregated form of pragmatically homogeneous text (PHT) corpora produced in situations of performed (or intended) communication, provide a cognitively revealing and empirically accessible collection of traces of processes whose resulting multi-faceted structures may serve as guideline for the cognitively motivated, empirically based, and computationally realized procedural modeling of *meaning constitution*. For cognitive models of natural language *understanding*, the systems theoretical view suggests to identify multi-level processes of *meaning constitution* with the acquisition of knowledge emerging from natural language processing, or enactive *learning*.

In accordance with 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) cognitive system beyond reality's material manifestations. This extension was based on the distinction of *immediate* from *mediate* system-environment relations which allowed to characterize *adaptation* as a process of necessarily identical space-time coordinates for SE relations, as opposed to *learning* as a process with that identity suspended, but in need of memory to establish that relation. Natural language *understanding* is a process of *meaning constitution* based on both, adaptation and learning, and modeled and performed as *enactive learning* by *semiotic cognitive information processing* (SCIP) systems. These are grounded in the triadic procedures of *semiosis* (among *sign, object* and *interpretant*), and its two-fold situatedness (of *discourse* and *description* constraints) corresponding to the double ontology of language signals as (physical) objects and (cognitive) meanings.

References

1. H. Atmannspacher: Complexity, Meaning, and the Cartesian Cut. In: Kornwachs/Jacoby [20], pp. 229–244.
2. J. Barwise/J. Gawron/G. Plotkin/S. Tutiya (eds): *Situation Theory and its Applications*, [Lecture Notes 2], Stanford University (CSLI), 1991.
3. J. Barwise/J. Perry: *Situations and Attitudes*, Cambridge, MA (MIT Press), 1983.
4. G. Bateson: *Steps to an Ecology of Mind. Collected Essays in Anthropology, Psychiatry, Evolution and Epistomology*, NewYork (Chandler), 1972.
5. G. Bateson: *Mind and Nature: A Necessary Unit*, NewYork (Dutton), 1979.
6. M. Born: Symbol and Reality. In: Born *Natural Philosophy of Cause and Change*, NewYork (Dover), 1964, pp. 215–234.
7. R. Carnap: Meaning and Synonymy in Natural Languages. In: Carnap *Meaning and Necessity*, Chicago (Univ. of Chicago Press), 1955, pp. 233–247.
8. J. L. Casti: Simple and Complex Models in Science. In: Kornwachs/Jacoby [20], pp. 209–228.
9. N. Chomsky: *Knowledge of Language: Its Nature, Origin, and Use*. Convergence, NY (Praeger), 1986.
10. R. Cooper/K. Mukai/J. Perry (eds): *Situation Theory and its Applications*, [Lecture Notes 1], Stanford University (CSLI), 1990.
11. K. Devlin: Infons and Types in an Information-Based Logic. In: [10], pp. 79–95.
12. K. Devlin: *Logic and Information*, Cambridge (Cambridge UP), 1991.
13. J. J. Gibson: *The Ecological Approach to Visual Perception*, Boston, MA (Houghton Mifflin), 1979.
14. J. A. Goguen: Semiotic Morphisms. `www.cs.ucsd.edu/users/goguen/papers/sm`, (1996), 2000.
15. C. Hartshorne/P. Weiss (eds): *Collected Papers of Charles S. Peirce*, Vol. 1–6, Cambridge, MA (Harvard UP), 1931–35.
16. M. Heidegger: *Sein und Zeit*, [English transl. by J. Stambough: *Being and Time*, NewYork (SUNY) 1996], Tübingen (Niemeyer), 1927, [10]1963.
17. P. Johnson-Laird/P. Wason (eds): *Thinking. Readings in Cognitive Science*, Cambridge/London (CUP), 1977.
18. P. N. Johnson-Laird: *Mental Models. Towards a Cognitive Science of Language, Inference, and Conscieousness*, Cambridge (CUP), 1983.
19. T. Kohonen: *Self-Organization and Associative Memory*. [Springer Series in Information Sciences], Berlin/Heidelberg/NewYork/London (Springer), [3]1989.
20. K. Kornwachs/K. Jacoby (eds): *Information. New Questions to a Multidisciplinary Concept*, Berlin (Akademie), 1996.
21. H. Maturana/F. Varela: *Autopoiesis and Cognition*, [Boston Studies in the Philosophy of Science 42], Dordrecht/Boston/London (Reidel), 1980.
22. H. R. Maturana: Biology of Language. The epistomology of reality. In: Miller/Lenneberg (eds): *Psychology and Biology of Language and Thought*, NewYork (Academic Press), 1978, pp. 27–64.
23. A. Mehler: *Textbedeutung. Eine prozedurale Analyse uns Reprsentation struktureller Ähnlichkeiten von Texten. (Diss. Trier)*. [Computer Studies in Language and Speech 5], Franfurt/Berlin/Bern (Lang), 2001.

24. A. Meystel: *Semiotic Modeling and Situation Analysis: an Introduction*, Bala Cynwyd, PA (AdRem Inc), 1995.
25. G. A. Miller/P. N. Johnson-Laird: *Language and Perception*, Cambridge (Cambridge UP), 1976.
26. C. W. Morris: *Writings on the General Theory of Signs*, The Hague/Paris (Mouton), 1938.
27. A. Newell: Physical Symbol Systems. *Cognitive Science*, 4: 135–183, 1980.
28. H. Pattee: Laws and constraints, symbols and languages. In: C. Waddington (ed): *Towards a Theoretical Biology IV*, Edinburgh (EUP), 1972, pp. 248–258.
29. H. Pattee: Universal Principles of Measurement and Language Functions in Evolving Systems. In: J. L. Casti/A. Karlqvist (eds): *Complexity, Language, and Life: Mathematical Approaches*, [Biomathematics 6], Berlin/Heidelberg (Springer), 1986, pp. 268–281.
30. H. Pattee: Simulations, Realizations, and Theories of Life. In: C. G. Langton (ed): *Artificial Life*. [Santa Fe Institute Studies in the Science of Complexity], Reading, MA (Addison Wesley), 1989, pp. 63–77.
31. H. Pattee: Evolving self-reference: matter, symbol, and semantic closure. *Communication and Cognition – Artificial Intelligence*, 12(1–2): 9–27, 1995.
32. H. Pattee: The Physics of Symbols and the Evolution of Semiotic Control. In: M. J. Coombs/M. F. Sulcoski (eds): *Control Mechanisms for Complex Systems: Issues of Measurement and Semiotic Analysis*, Las Cruces, NM (NMSU), 1996, pp. 9–25.
33. C. S. Peirce: Pragmatism in Retrospect: A Last Formulation. In: Buchler (ed): *The Philosophical Writings of Peirce*, (CP 5.11–5.13), NewYork (Dover), 1906, pp. 269–289.
34. M. F. Peschl/A. Riegler: Does Representation Need Reality? In: Riegler et al. [60], pp. 9–17.
35. R. Pfeiffer/Z. Schreter/F. Fogelman-Soulié/L. Steels (eds): *Connectionism in Perspective*, Amsterdam (North Holland), 1989.
36. H. Putnam: *Representation and Reality*. Cambridge, MA (MIT Press), ^{4}1991.
37. U. Ratsch/I.-O. Stamatescu: Introduction. In: Ratsch et al (eds) *Intelligence and Artificial Intelligence. An Interdisciplinary Debate*, Berlin/Heidelberg (Springer), 1998, pp. 1–21.
38. G. Rickheit/L. Sichelschmidt: Mental Models: Some Answers, some Questions, some Suggestions. In: G. Rickheit/C. Habel (eds): *Mental Models in Discourse Processing and Reasoning*, [Advances in Psychology 28], Amsterdam/NewYork (Elsevier/North Holland), 1999.
39. G. Rickheit/L. Sichelschmidt: Mental Models: Some Answers, some Questions, some Suggestions. In: [38], pp. 9–40.
40. B. Rieger: Eine 'tolerante' Lexikonstruktur. Zur Abbildung natürlich-sprachlicher Bedeutungen auf 'unscharfe' Mengen. *Zeitschrift für Literaturwissenschaft und Linguistik*, 4(16): 31–47, 1974.
41. B. Rieger: Bedeutungskonstitution. Einige Bemerkungen zur semiotischen Problematik eines linguistischen Problems. *Zeitschrift für Literaturwissenschaft und Linguistik*, 7(27/28): 55–68, 1977.
42. B. Rieger: Theorie der unscharfen Mengen und empirische Textanalyse. In: Klein (ed): *Methoden der Textanalyse*, [medium literatur 3], Heidelberg (Quelle & Meyer), 1977, pp. 84–99.
43. B. Rieger: Semantische Dispositionen. Prozedurale Wissenstrukturen mit stereotypisch repräsentierten Wortbedeutungen. In: Rieger (ed): *Dynamik der Bedeutungskonstitution. Beiträge zur prozeduralen Semantik der natürlichen Sprache*. [Papiere zur Textlinguistik 46], Hamburg (Buske), 1985, pp. 163–228.
44. B. Rieger: *Unscharfe Semantik. Die empirische Analyse, quantitative Beschreibung, formale Repräsentation und prozedurale Modellierung vager Wortbedeutungen in Texten*, Frankfurt/Bern/Paris (Lang), 1989.
45. B. Rieger: Fuzzy Modellierung linguistischer Kategorien. In: Feldweg/Hinrichs (eds): *Lexikon und Text*, [Lexicographica Series Maior 73], Tübingen (Niemeyer), 1996, pp. 155–169.
46. B. Rieger: Bedeutungskonstitution und semantische Granulation. In: Pohl (ed): *Prozesse der Bedeutungskonstruktion*, [Sprache, System, Tätigkeit 40], Frankfurt/Berlin/Bern (Lang), 2002, pp. 407–444.
47. B. B. Rieger: Fuzzy Structural Semantics. On a generative model of vague natural language meaning. In: Trappl/Hanika/Pichler (eds): *Progress in Cybernetics and Systems Research*, Vol. V, Washington/NewYork/London (Wiley & Sons), 1979, pp. 495–503.

48. B. B. Rieger: Feasible Fuzzy Semantics. On some problems of how to handle word meaning empirically. In: Eikmeyer/Rieser (eds): *Words, Worlds, and Contexts. New Approaches in Word Semantics*, [Research in Text Theory 6], Berlin/NewYork (de Gruyter), 1981, pp. 193–209.

49. B. B. Rieger: Lexical Relevance and Semantic Disposition. On stereotype word meaning representation in procedural semantics. In: Hoppenbrou wes/Seuren/Weijters (eds): *Meaning and the Lexicon*, Dordrecht (Foris), 1985, pp. 387–400.

50. B. B. Rieger: Distributed Semantic Representation of Word Meanings. In: Becker/Eisele/Mündemann (eds): *Parallelism, Learning, Evolution. Evolutionary Models and Strategies, WOPPLOT-89*, [Lecture Notes in Artificial Intelligence 565], Berlin/Heidelberg/NewYork (Springer), 1991, pp. 243–273.

51. B. B. Rieger: Reconstructing Meaning from Texts. A Computational View on Natural Language Understanding. In: Raubold (ed): *Innovative Developments and Applications of Microelectronics and Information Technology.* Proceedings 2nd German–Chinese Electronics Week Shanghai (GCEW-91), Berlin/Offenbach (VDE Verlag), 1991, pp. 193–200.

52. B. B. Rieger: Meaning Acquisition by SCIPS. In: Ayyub (ed): *ISUMA-NAFIPS-95*, [Joint Intern. Conf. on Uncertainty Modeling and Analysis, North American Fuzzy Information Processing Society], Los Alamitos, CA (IEEE Computer Society Press), 1995, pp. 390–395.

53. B. B. Rieger: Situations, Language Games, and SCIPS. Modeling semiotic cognitive information processing systems. In: Meystel/Nerode (eds): *Architectures for Semiotic Modeling and Situation Analysis in Large Complex Systems*, 10th IEEE Symposium on Intelligent Control, Bala Cynwyd, PA (AdRem), 1995, pp. 130–138.

54. B. B. Rieger: Situation Semantics and Computational Linguistics: towards Informational Ecology. A semiotic perspective for cognitive information processing systems. In: Kornwachs/Jacoby [20], pp. 285–315.

55. B. B. Rieger: Computational Semiotics and Fuzzy Linguistics. On meaning constitution and soft categories. In: Meystel (ed): *A Learning Perspective.* International Conference on Intelligent Systems and Semiotics (ISAS-97), [NIST Special Publication 918], Washington, DC (US Gov. Print. Office), 1997, pp. 541–551.

56. B. B. Rieger: Semiotics and Computational Linguistics. On Semiotic Cognitive Information Processing. In: Zadeh/Kacprzyk (eds): *Computing with Words in Information/Intelligent Systems*, [Studies in Fuzziness and Soft Computing 33-1], Heidelberg/NewYork (Physica), 1999, pp. 93–118.

57. B. B. Rieger: Computing Granular Word Meanings. A fuzzy linguistic approach in Computational Semiotics. In: P. P. Wang (ed): *Computing with Words*, [Wiley Series on Intelligent Systems 3], NewYork, NY (Wiley & Sons), 2001, pp. 147–208.

58. B. B. Rieger/C. Thiopoulos: Situations, Topoi, and Dispositions. On the phenomenological modelling of meaning. In: Retti/Leidlmair (eds): *5.Österreichische Artificial-Intelligence-Tagung, Innsbruck-Igls*, [KI–Informatik-Fachberichte 208], Berlin/ Heidelberg/ NewYork (Springer), 1989, pp. 365–375.

59. B. B. Rieger/C. Flores/D. John: The SCIP system-environment procedural test page. `www.ldv.uni-trier.de:8080/rieger/SCIP.html`, 2002 [in preparation]

60. A. Riegler/M. Pesch/A. von Stein (eds): *Understanding Representation in the Cognitive Science*, NewYork/Boston (Kluwer Academic/Plenum), 1999.

61. H. Ritter/T. Kohonen: Self-Organizing Semantic Maps. *Biological Cybernetics*, 61: 241–254, 1999.

62. F. d. Saussure: *Cours de Lingistique Générale* (1916). Kritische Edition von R.Engler. Wiesbaden (Backhaus), 1967.

63. H. A. Simon: *The Sciences of the Artificial*. Cambridge, MA (MIT Press), ^{2}1982.

64. A. Tarski: Der Wahrheitsbegriff in den formalisierten Sprachen. *Studia Philosophica*, 35/36(1): 261–405, 1935.

65. A. Tarski: The semantic conception of truth and the foundation of semantics. *Journ. of Philosophy and Phenomenological Research*, (4): 341–375, 1944.

66. T. Winograd/F. Flores: *Understanding Computers and Cognition: A New Foundation for Design*, Norwood, NJ (Ablex), 1986.

67. L. A. Zadeh: Fuzzy Sets. *Information and Control*, 17(8): 338–353, 1965.

68. L. A. Zadeh: Quantitative Fuzzy Semantics. *Information Science*, 3: 159–176, 1971.

69. L. A. Zadeh: PRUF – a meaning representation language for natural languages. *Int. Journ. Man-Machine-Studies*, (10): 395–460, 1978.

70. L. A. Zadeh: TEST-Score Semantics for Natural Languages and Meaning Representation via PRUF. In: Rieger (ed): *Empirical Semantics I*, [Quantitative Linguistics 12], Bochum (Brockmeyer), 1981, pp. 281–349.

71. L. A. Zadeh: Toward a Theory of Fuzzy Information Granulation and its Centrality in Human Reasoning and Fuzzy Logic. *Fuzzy Sets and Systems*, 90(3): 111–127, 1997.

72. T. Ziemke: Rethinking Grounding. In: Riegler et al. [60], pp. 49–68.