

On Understanding Understanding.

Perception-based processing of NL texts in SCIP systems, or meaning constitution as visualized learning.

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Abstract: *Inspired by information systems theory, Semiotic Cognitive Information Processing (SCIP) is grounded in (natural/artificial) system-environment situations. SCIP systems' knowledge-based processing of information makes it cognitive, their sign and symbol generation, manipulation, and understanding capabilities render it semiotic. Based upon structures whose representational status is not a presupposition to, but a result from recursive processing, SCIP algorithms initiate and modify the structures they are operating on to realize (rather than simulate) language understanding by meaning constitution. Thus, the symbolic (de)composition of propositional structures in traditional semantics is complemented by SCIP, which models learning and understanding dynamically by visualizing what is understood in a perception-based, sub-symbolic, multi-resolutional way of processing natural language discourse. An experimental 2-dim scenario with object locations described relative to a mobile agent's varying positions allows to test SCIP systems' performance against human natural language understanding in a controlled way¹.*

Keywords: Computational semiotics, discourse un-

derstanding, meaning constitution, semantic space, fuzzy modeling, symbol grounding, dynamics, systems theory, visualization, quantitative linguistics.

I. INTRODUCTION

In terms of information systems theory, life may be understood as the ability to survive by adapting to changing requirements in the real world. Living systems do so by way of processing information they receive or derive from relevant portions of their surrounding environments, of learning from their experience, and of changing their behavior accordingly. In contrast to other living systems which transmit experiential results of environmental adaptation only biogenetically² to their descendants, human information processing systems have additional means to convey their knowledge to others. In addition to the vertical transmission of system specific (*intraneous*) experience through (biogenetically successive) generations, mankind has developed complementally effective *horizontal* means of mediating specific and foreign (*extraneous*) experience and knowledge to (biogenetically unrelated) fellow systems within their own or any later generation.

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¹The implementation of the SCIP system-environment testbed is due to my PhD-students, Christoph Flores and Daniel John, whose design and programming proficiencies are thankfully appreciated.

²According to standard theory there is no direct genetic coding of experiential results but rather indirect transmission of them by selectional advantages which organisms with certain genetic mutations gain over others without them to survive under changing environmental conditions with higher reproduction.

A. Process and Result

This is made possible by a *semiotic* move based on representations that allow not only to distinguish *processes* from *results* of experience, but also convert the essentially transient status of experiential results to some more stable though dynamic cognitive entities of *knowledge*. These can be retrieved, activated, re-used, modified and improved by later processes and their results in *learning*.

Vehicle and medium of this move is a particular kind of *representation*. Based upon more or less complex sign systems which constitute *languages* to form more or less abstract compositional structures or *textures*, these may be realized in processes of communicative exchange, called *actualization*³. Such *textures* function – whether internal to a system (as its *knowledge*) or external to it (as language *texts* or *discourse*) – like virtual environments⁴ to any system properly *attuned*, i.e. being able to recognize and interpret them.

B. Mediate and Immediate

In terms of information system theory, *virtuality* can be characterized by the fact that it dispenses with the identity of space and time coordinate values for a system and its environment which normally prevails for this relation when qualified to constitute *reality* [3, pp. 287]. The hypothesis is that the dispensation of this identity (of value pairs) is not only conditional for the possibility to distinguish (mutually and relatively independent) *systems* from their *environments*, but also to establish a systems theoretical perspective on *representations*. This opens new vistas on language understanding and how it can be modeled apart from propositional decomposition of language structures.

Immediate or space-time-identical system-environment settings can be distinguished from *mediate*

³Term borrowed from *Situation Semantics* [1, pp. 60] where *abstract*, *actual* and *factual* signify levels of typified (ontological) specificity in characterizing *events*, *state-of-affairs*, *courses-of-events*, *situations* etc.

⁴Simon's [2] remark "There is a certain arbitrariness in drawing the boundary between inner and outer environments of artificial systems. . . . Long-term memory operates like a second environment, parallel to the environment sensed through eyes and ears" (pp. 104) is not a case in point here. As will become clear in what follows, his distinction of *inner* (memory structure) and *outer* (world structure) environments of a system misses the special *semiotic* quality of natural language signs whose twofold environmental embedding (textual structure) cuts across the *inner/outer* distinction, resolving both, memory and world structures in becoming representational for each other.

or space-time-dispensed system-environment situations. The former may be characterized (and modeled) by some stimulus-response form of interaction whereas the latter are tied to some intermediate stratum of a particular format which needs actualization in order to be realized. Its representational function seems to evolve in the very process of actualizing which is itself *immediate* in the sense that the system concerned has to have physical access to that stratum and its particular format in order to let it represent something else or become *mediate* in the above specified sense. The distinction corresponds to the twofold status which semioticians like SAUSSURE [4] and PEIRCE [5] had long identified as being characteristic of *signs* and *symbols* as well as *text* and *discourse*. These can both be perceived as some physical language material (consisting of *components*) and also be realized as language structure (having *meaning*) which is to be *understood*.

It is this double identity (or *ontology*) of language signs and symbols which calls not only for a two-level modus of actualization but also for a multi-level modeling approach to realize *understanding* by machine. Taking up conceptions developed in *situation theory* [1, 6], the *semiotic* approach to understand language *understanding* may tentatively be characterized as follows:

For information processing systems appropriately adapted (*tuned*) to their environments the process of *actualization* consists essentially in a twofold embedding

- ▷ to perceive the space-time-identity of pairs of *immediate* system-environment coordinates which will let the system experience the material properties of texts as composed of *signs* (i.e. by functions of *physical* presentation and *mutually homomorphic* appearance). These properties apply to the percepts of language structures accessible to a system in particular *discourse situations*, and
- ▷ to realize the representational relatedness 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 *emergence*, *identification*, *organization*, *representation* of structures). These apply to the comprehension of language structures as multi-level and multi-dimensional entities (re)cognized by a system to form the *described situations* which can be *understood*.

C. Knowledge and Cognition

In terms of cognitive theory realizational functions like *identifying* structures, *interpreting* signs, and *understanding* meanings translate to processes which extend the segments of reality accessible to a living (natural and possibly artificial) information processing system. This extension applies to both the *immediate* and *mediate* relations which a system establishes by adaptive *learning* and emergent *understanding* based on its own innate or acquired *structuredness*, its processing *capabilities*, and its *knowledge*. Knowledge based information processing therefore became the paradigm for modeling *cognition*. Traditional approaches to cognition have tried to provide the knowledge externally as propositionally formatted symbol representations and consequently had to exclude the dynamics of change and self-organizing which are characteristic of *adaptation* and *learning*. More recent models of cognitive information systems are designed to model attunement to (textual) environments, endowed with knowledge acquisition, modification, and representation capabilities to allow for the dynamic processing of representational data or sign structures to actualize relevant information. These are referred to as *semiotic cognitive information processing* (SCIP) systems [7] one of which will be dealt with here.

Following these introductory remarks (I) will be a short survey (II) of what cognitive models of meaning have dealt with so far. Some essentials of SCIP systems as part of a future *dynamic image generating semantics* (DIGS) will (III) characterize the computational semiotics approach which – for the purpose of modeling – allows to separate the process of *understanding* referential expressions from *generating* them in describing real world entities. The model will be realized in three steps of increasing procedural concretion of processing by formal definition as *morphisms* and *constraints* (IV), their specified instantiations as *setting* and *experiment* (V), and their implementations as *process* and *measurement* (VI) with test results to illustrate the model’s performance. Finally, a *summary* and outlook to *future work* (VII) will conclude the paper.

II. COGNITIVE MODELS OF MEANING

It is common practice in cognitive modeling and mathematical semantics [1, p. 57] to identify

the real world with the (symbolic) structure that represents it. From a semiotic point-of-view, this identification is hiding rather than revealing what makes a structured *sign* aggregate represent or stand for (*symbolize*) something else.

A. Reality, Perception, and Representations

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 [8] that the relationship between the real world or objective *reality* (R) of observable entities external to a cognitive system, and the perception of such entities by observations which constitute a 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. These 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 and/or experiential 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-environment from 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 [9]. This is a consequence of self-organizing, dynamic, autopoietic systems [10] 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 realm of entities. 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 overcome the traditional mind/matter duality. In

view of representations like natural languages, the *endo-exo* distinction allows for a semiotically more adequate approach to entities whose observable reality provides for an experiential perception which is also the precondition for their *understanding* (and the modeling of it).

B. Semantic Theory, Meaning, and Understanding

Theoretical and computational linguistics – mediated by (language) philosophy, (formal) logics, and (discrete) mathematics – have clearly dominated research and explicative theory development. They decided on how natural languages (NL), their (compositional) structures, and their (semantic) functions are to be understood and explicated as symbol manipulation and transformation systems. NL communication has long been conjectured to consist of what only recently the cognitive sciences have identified as a complex of multi-level processes. These were conceived as operating on (world, linguistic, situational) knowledge which has to be considered conditional for any information processing. However, the knowledge bases (KB) designed to comply with these conditions were hypothesized as physical symbol systems [2, 11] whose static conception of structure proved to be unable to adapt to changing conditions (learning). Some of the problems [12] that cognitive modeling along these lines encountered since are due to the declarative (i.e. symbolic, compositional, propositional) *formats* employed and the (deterministic, rule-based, modular) *procedures* chosen in generating, forming, and manipulating linguistic concepts like morphemes, syllables, words, phrases, sentences, texts, and their meanings. As these tend to be construed of clear-cut elements (aggregates, structures, relations, functions, processes, etc.) of systems of language entities, their crisp and determinate definitions do not comply with the way they are perceived which is variable, context dependent, fuzzy, and possibilistic in nature.

In order to understand the dynamics of how natural languages serve the communicative purposes they do, fuzzy [13, 14] and procedural modeling [15] approaches to semiotic systems [16, 17] and NL understanding [18, 19] have advanced some ideas [20, 21] for a computational theory of cognitive processing of fuzzy percepts. Conceived as a multi-layered process of structure identification and dynamic representation, the fuzzy modeling techniques em-

ployed in SCIP systems so far allow for (numerical, sub-symbolic, distributed, non-propositional) formats whose (parallel, pattern-based, quantitative) computation results in (the emergence of) meanings as enactment of labeled processes of choice restriction [22]. Accordingly, *meanings* are the outcome rather than the presuppositions of processing [23], whose modeling is a form of *realization* rather than *simulation* [24]. It appears that a perception-based simulation of processes (of constraint detection and representation) may bring about results which realize *meaning constitution* and *understanding* (of symbolic structures) as grounded in these very processes.

One of the most severe problems though, arising with this kind of non-linguistic models of language understanding is how their performance and their results may be evaluated and tested in an intersubjectively agreeable and preferably empirical way. Generating images of what declarative referential language expressions describe could be a solution, provided that the semantic contents detected computationally are a result of and not a presupposition to the detection process.

III. SCIP SYSTEMS AND DIG SEMANTICS

Based on the above (as yet) fragments of a computational theory of cognitive processing of fuzzy percepts, the contours of a *dynamic image generating semantics* (DIGS) can be identified which may eventually be able to cope with variability and vagueness, adaptivity and learning, emergence and plasticity of *knowledge* and *understanding* in a unifying and comprehensive way. As a fully-fledged theory it would comprise perception-based, sub-symbolic parts side by side with rule-based, symbolic components, the former ideally grounding the latter. Anticipating this combination in a weaker sense, the setup of the modeled *semiotic cognitive information processing* (SCIP) system is complemented by a component which employs rule-based, symbolic processing for deterministic language generation purposes. As these techniques have long been developed and applied in natural language processing (NLP) in general and computational linguistics (CL) in particular, they are well understood and ready to be used.

In our setup they will be employed to generate the language material (texts) describing real world

situations in a formally controlled, i.e. rule-based, determinate and symbolic way. This training material will then be submitted to an equally controlled, though simulative way of processing which is perception-based, non-determinate (stochastic), sub-symbolic (numerical) and hypothesized to model a *symbol grounding* process of language *understanding* [25, 26]. Suitable visualization of processing results will allow for an *ad oculos* test and comparison with the real world scenario described by the texts processed.

A. Knowledge, Memory, and Models

Most cognitive scientists agree that cognition is a form of information processing. Models of cognition therefore are inspired by *information systems theory* and based upon (natural or artificial) system-environment situations. Any system whose processing of external, environmental data (input) is determined by its own internal structuredness will generally produce some *information* (output) relative to both, its internal and external conditions. As soon as the flow of input data consists not only of signals but also of signs or symbol aggregates, the simple system-environment relation will become more complex, oscillating between *immediate* and *mediate* as characterized in system theoretical terms. This is due to the double ontology of signs which are not only perceived but have to be recognized as representations in order to be processed accordingly, i.e. interpreted as standing for something else that the perceivable signal is not.

Traditional models of *cognitive* information processing try to account for this double ontology of signs and symbols – which are physically *real* like data but in addition also have *meaning* – by providing the processing system with the necessary information via arbitrarily complex representations (sets, structures, systems) of sign-meaning correspondences, named knowledge-bases. KBs extend the system’s data processing capabilities to *cognitive*, i.e. knowledge-based processing in generating, manipulating, and interpreting sign and symbol aggregates of different kinds. These comprise linguistic knowledge in form of *grammars* (rules of *syntax* and *semantics*), and world knowledge in form of *network structures* (like *frames*, *scripts*, and *scenes*).

Conceived as being externally attributable to the modeled system and therefore assembled and formatted by the model designer, KBs obviously serve

to model functions which are considered essential to the original or natural cognitive systems and their structure (i.e. knowledge and memory). The assumption behind most KBs, however, that knowledge is propositional and its only format of representation is truth-functional, rule-based, and symbolic in nature (*linguistic transparency*) has been refuted [7, pp. 350]. It was revised in so far as the process of language understanding can neither be identified with sentence parsing nor with the inverted process of generating natural language expressions applying formal syntax and semantics as provided by computational linguistics.

B. Cognitive Information Processing

In order to let traditional models of *cognitive language information processing* (CLIP) become *semiotic*, their knowledge and memory functions have to be conceived as procedural and internal to the systems changing their character from static determination to dynamic flexibility (Fig. 1: processing loops). Additionally, the representational format for *knowledge structures* and *memory functions* should facilitate adaptation to changing environmental and processing conditions (*learning*), and enable identification in changing contexts (*efficiency*) for a singular system concerned, as well as among a plurality of systems interacting by means of externalized sign representations (*communication*).

Allowing for variable, ill-defined, underdetermined data to be processed, and enabling the self-organized constitution (emergence) of vague and fuzzy entities to be represented and operated on, *semiotic cognitive information processing* (SCIP) is based on well-defined procedures which can handle imprecision in a precise way. SCIP systems’ ability comprises their performance in knowledge-based information processing and representing its results [27], organizing these representations by activating others from prior processing [28], constituting meanings [29], allowing for (semantic) inferencing [30], and planning [31] by selecting from organized and represented dispositions [32], and modifying them according to changing conditions, results, and states of evolving system-environment adaptedness [33]. Based on NL structures, SCIP performance is a form of complex, multi-resolutional information processing. As a process of *meaning constitution* it is tied to (and may even be identified with) language *understanding* [34] or *meaning acquisition*.

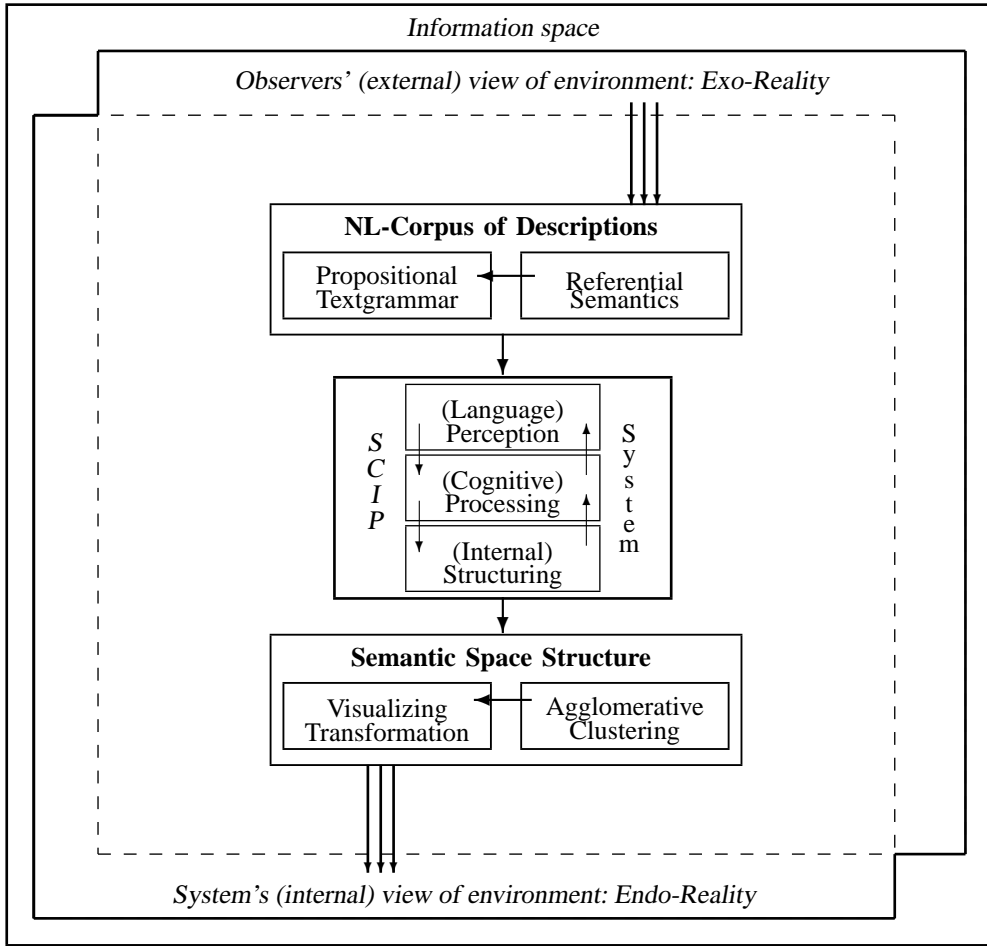


Fig. 1. Schema of test layout to compare the situated SCIP system's (enigmatic) internal-view (*endo-reality*) resulting from its (well-defined) processing, against the observer's (well defined) external-view (*exo-reality*) which traditional, symbol based, cognitive modeling identifies prematurely with the (enigmatic) processes underlying natural language understanding. Whereas the referential semantics and propositional text grammar are employed to generate PHT corpora of NL descriptions of (real world) situations, the subsymbolic, two-level processing of these descriptions yield the SCIP system's semantic space structure. Its algorithmic visualization (Fig.9) allows for a comparison with the external observers' view of real world situations (Fig.3) which traditional models describe by grammatically correct and semantically true propositions⁸ encoded as *referential meaning* or *informational content*.

Whenever the *meaning of signs* is not a presupposition to but a result from algorithmic processing of (symbolic) data whose representational status (like in NL discourse) is commonly accepted, then these *learning* algorithms – being able to initiate and modify the structures they are operating on – may qualify as *semiotic* and thereby as part of *computational semiotics*.

C. Perception-based Discourse Understanding

The SCIP system's approach to discourse understanding is – very much like modeling *vision* [35] – essentially *perception based*. As such it complements the declarative, symbolic (de)composition of propositional structures exercised by traditional NL semantics in a way which allows for the dy-

namics these lack. Provided by procedural definitions of quantitative, sub-symbolic and flexible pattern identification, representation, and manipulation, their flexibility might become a central part of an evolving *dynamic image generating semantics* (DIGS). Its adaptivity would essentially depend on the SCIP system's format of non-symbolic, distributed numerical representations whose processing allow new representations to emerge when needed. They are tying the system to those segments of the real world which the language expressions are a part of and – when processed properly – con-

vey information about as their meanings⁵. They do so both, according to their grammaticality and propositional contents as determined in a formally specified sense *external* to the system, and according to the system’s own or *internal* understanding based upon the non-propositional, syntagmatic and paradigmatic regularities in textual structures which can also be visualized. To achieve this, DIGS would have to formalize these ties in two ways: as a deterministic system of grammatical rules for semantic and syntactic constraints to generate true and correct language *descriptions* of real world entities, and inversely – independent from grammatical rules and their symbolic representations – as a class of restrictions that are typified by (soft) constraints, modeled as procedures which produce (fuzzy) relations represented as (word type/ numerical value) distributions. As the former can straight forwardly be provided by computational linguistics, the latter are not just another instance of transformed data representation but – as they result from non-symbolic, numerical computation – a new type of structural representation associating emergent entities (concepts) with observable entities (objects/signs) to realize what may be named their *understanding*.

IV. MORPHISMS AND CONSTRAINTS

Being grounded in system-environment situations, SCIP systems may formally be characterized by *morphisms*⁶ which allow to represent meanings and functions of language entities as evolving from multi-level decompositions of cycles of constraint processing (referring here and below to Fig. 2) operating on and modifying the structured entities concerned [7, p. 380]. Thus, morphisms designate a very general type of relatedness which allows to characterize the procedural notion of *semioticity* formally on a rather abstract level. Morphisms call

⁵The meaning conveyed cannot always be represented in a language independent way, e.g. by observable operations/processes enacted without being understood prior to their (re)presentation as semantic contents. This is also why traditional cognitive approaches easily accept linguistic analyses of propositional language structure as only explication (*linguistic transparency*) of *understanding*, and why linguistic semantics in turn appeals to formal logics as an available format for the representation of declarative NL expressions’ predicative functioning.

⁶The concept of *morphism* [36] is employed because it captures a notion of generality as a type of abstract relatedness whose possible instantiations (as mappings, relations, partial or total functions, etc.) due to yet unknown conditions of definiteness cannot and need not be decided on.

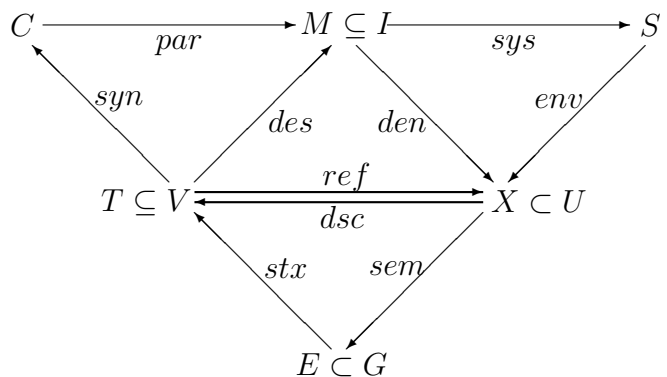


Fig. 2. Diagram of morphisms mapping vocabulary items (*signs*⁷) $z \in T \subseteq V$ onto meaning points or intensions $p \in M \subseteq I$, allowing their *designation* $des \subseteq V \times M$ (*cognitive interpretants*⁷) to be reconstructed as composition $par \circ syn$. The *denotation* $den \subseteq M \times X$ relating intensions to real world entities, may be reconstructed as composition $env \circ sys$ of the attuned system’s constraints’ relation $sys \subseteq M \times S$ and the environmental segment’s constraints’ relation $env \subseteq S \times X$. Thus, den relates (fuzzy) intensions $p \in M \subseteq I$ to real situations by classifying (fuzzy) subsets X of entities (*objects*⁷) $x \in X \subseteq U$ in the *universe of discourse* due to types of (abstracted) situational uniformities $s \in S$ common to both. Hence, the *reference* relation $ref \subseteq T \times X$ is reconstructed as composition $den \circ des$, whereas its inverse or *description* relation $dsc \subseteq X \times T$ is (re)constructed as composition $stx \circ sem$ of $sem \subseteq X \times E$ and $stx \subseteq E \times T$, relating (*real*) entities (*objects*) $x \in X \subseteq U$ via (formal) language expressions (logical *interpretants*) $e \in E \subseteq G$ of the *grammar* to *semantically* true and *syntactically* correct (natural) language strings (*signs*) $z \in T \subseteq V$.

for further specifications which in turn may be instantiated in a variety of ways. Some of these will permit operational application in SCIP-like settings of which a few might even realize PEIRCE’s conception of *semiosis*⁷.

A. Decomposition I

The first level of decompositions apply to both the *reference* and the *description* morphisms ref and dsc (Fig. 2).

A. 1 For the process type of *describing* entities in the *universe of discourse*, the morphism $dsc : X \rightarrow T$ is introduced (Fig. 2). In order to generate semantically true sem and syntactically correct stx natural language expressions $T \subseteq V$ from a given vocabulary, the decomposed morphism $dsc = stx \circ sem \subseteq X \times T$ will have to be instantiated. This instantiation can theoretically be specified and algorithmically determined by formal expressions $e \in E \subseteq G$ of grammatical adequacy as provided by

⁷“By *semiosis* I mean [...] an action, or influence, which is, or involves, a coöperation of *three* subjects, such as *sign* [$z \in T \subseteq V$], its *object* [$x \in X \subseteq U$], and its [cognitive: $p \in M \subseteq I$ or logical: $e \in E \subseteq G$] *interpretant*, this tri-relative influence not being in any way resolvable into actions between pairs.” [5, p.282]

computational linguistics. The morphisms stx and sem define a notion of constrained syntactic *correctness* and semantic *truth* of propositional structures. These are *dynamically generated* to describe real world entities $x \in X \subset U$ in a controlled way to form NL expressions in texts $z \in T \subseteq V$. Assembled into collections of increasing size, this language material $T \subseteq V$ forms PHT-corpora (of *pragmatically homogeneous texts*) whose semantic contents (*meaning*) are the described situations these texts refer to.

A. 2 For the inverse process type of *understanding* natural language expressions $T \subseteq V$ the *referencing* morphism $ref : T \rightarrow X$ is introduced (Fig. 2). Due to the *designative* and *denotative* constraints des and den hypothesized to constitute referential meaning, the decomposition $ref = den \circ des \subseteq T \times X$ allows to instantiate the *reference* morphism relating language entities $T \subseteq V$ to specified real world entities $X \subset U$ in the universe, i.e. constituting these NL expressions' meanings.

However, whereas the *description* process can be based on externally defined formal grammars G whose expressions of symbol manipulation rules $E \subseteq G$ fully determine the language generation, the meanings or concepts $M \subseteq I$ which instantiate the *referencing* process cannot be provided from the outside without losing the chance to see the system's own, internal way of meaning constitution diverge from the external observers' view and to model its possible approximation to the model designers' understanding. In order to keep that possibility and let the model produce such potential divergence, another level of decomposition has to be introduced to allow instantiation of the as yet unspecified morphisms des and den .

B. Decomposition II

The second level of decompositions apply again to both the *designation* and the *denotation* morphism des and den (Fig. 2).

B. 1 As a relational notion of correspondence between observable language elements $z \in T \subset V$ and realized entities of an abstract conceptual nature $p \in M \subseteq I$, the *designation* morphism $des = par \circ syn \subseteq T \times M$ is defined as a composition of principles which restrict the combinability of language entities in a way universal to all natural languages. These principles characterize natural

languages' ability to form discernable entities and patterns recursively by aggregational or *syntagmatic* (syn) and selective or *paradigmatic* (par) restrictions. These can be instantiated by implementable semiotic algorithms for the recursive computation of the combinatorial constraints syn and par and their multi-layered, multi-resolutional representation $y \in C$ in (patterns of) distributions of (emergent and abstract) entities $p \in M \subseteq I$.

B. 2 For the abstract entities $p \in M \subseteq I$ which are being realized conceptually to relate to real world entities $x \in X \subset U$ in the universe, the *denotation* morphism $den = env \circ sys \subseteq M \times X$ is defined as a composition of structural constraints inherent to the system sys on the one hand and to the environment env on the other. They couple the system and its environment to each other and determine their mutual structuredness, restricting the range of components in typified situations $s \in S$ common to both. Instantiated as a cluster analyzing algorithm, the sys constraints provide the internal or *endo-view* a SCIP system may obtain of its environment in collecting structural information (*uniformities*) as gathered from processing the discourse that describes it. Visualizing these *uniformities* is a transformation algorithm which instantiates the sys morphism to yield an image of the real world situation comparable to $x \in X \subset U$.

C. Natural Language and Symbol Grounding

In order to demonstrate the suggested SCIP system's potential and factual discourse *understanding* capability, it has to be made more concrete procedurally. The base for such a concretion will be *language* or rather natural language *discourse* in its structured form. It functions as *structural coupling* [10], which not only relates an information processing *system* to its embedding *environment* (and vice versa), but also serves to instantiate the hypothesized *description* and *reference* morphisms by different processes due to the *semiotic* functions that characterize situated natural language discourse. Whereas the process $dsc : X \rightarrow T$ of describing real world entities $X \subset U$ by NL expressions $T \subseteq V$ can and will be controlled by means of formal grammars (*syntax* and *semantics*) $dsc = stx \circ sem \subseteq X \times T$, the process $ref : T \rightarrow X$ of referencing or how NL expressions $T \subseteq V$ can stand for or represent some real world entities $X \subset$

U is still enigmatic. Its hypothesized reconstruction $ref = den \circ des \subseteq T \times X$ as *understanding* process composed of meaning constitution (*mental imaging*) $des = par \circ syn \subseteq T \times M$ and structure visualization (*symbol grounding*) $den = env \circ sys \subseteq M \times X$ needs to be specified.

To ease the burden of declaring and outlining the correspondences between the formal types of processes introduced so far and their procedural instantiations, the measurements of constraints and their algorithmic implementation, up to computed results and their visualizations, we will in what follows confine ourselves to an experimental setting chosen to limit the SCIP system’s testable performance with reference to earlier publications where appropriate.

V. SETTING AND EXPERIMENT

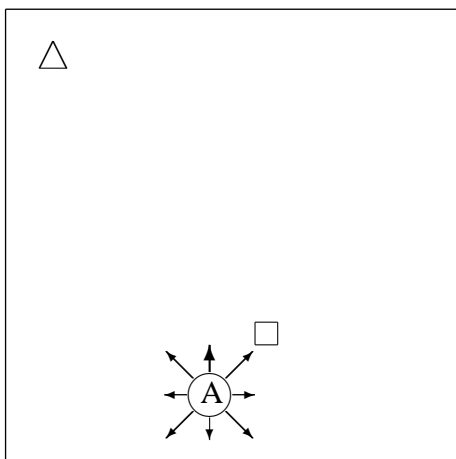


Fig. 3. 2-dim *reality* of stationary object locations \triangle and \square with mobile agent A, oriented North. The agent’s system-positions relative to the object-locations determine the propositional descriptions of SPOL relations in simple, declarative sentences⁸. These are composed of four *core predicates* (*left, right, front, behind*) modified by five *hedge predicates* (two first order: *near, far*; three second order: *extremely, very, rather*) as specified by the formal *grammar* (syntax Tab. IV and *semantics* Tab. V) which define and control the semantic content of the generated *descriptions* (PHT corpus), not however the way it is processed for *understanding* by the SCIP model.

Modeling *understanding* as a particular form of information processing within a system-environment frame (Fig. 1) is to take advantage of running real-time process simulation tests. For the purpose of experimentally testing *semiotic* processes, however, their situational complexity has to be reduced by abstracting away irrelevant constituents, hopefully without oversimplifying the

issue and trivializing the problem. Therefore, a simple 2-dimensional *real world* scenario (Fig. 3) was devised as a reference plane with stationary objects $\triangle, \square \in X \subset U$ (environment) and an oriented mobile agent $A \in X \subset U$ (system) whose trajectories can be used to generate verbal descriptions of the objects’ locations relative to the agent’s changing system positions (SPOL relations) in simple declarative sentences⁸. Thus, the propositional form of natural language predication will be used solely to control the contents of the natural language descriptions generated as training material, not, however, to determine the way it is processed to model its *understanding*. Moreover, the scenario determines the overall situation and provides for the observer’s external view of *reality*, allowing the model designer to distinguish what the SCIP system might grasp (or *understand*) of it in processing the NL discourse which describes that scenario.

$SCIP_{System}$	$= \{\mathcal{O}, \mathcal{B}, \mathcal{W}, \mathcal{F}, \mathcal{K}\}$
<i>Orientation</i> \mathcal{O}	$:= \{\vec{N}=(0, 1), \vec{S}=(0, -1)$ $\vec{O}=(1, 0), \vec{W}=(-1, 0)\}$
<i>Mobility</i> \mathcal{B}	$:= \{g(0, 1), g(1, 1), g(1, 0),$ <i>(pace and</i> $g(1, -1), g(0, -1), g(-1, -1),$ <i>direction)</i> $g(-1, 0), g(-1, 1) : g = 1\}$
<i>Perception</i> \mathcal{W}	$:= \{K := \{k_i\}, L := \sum_{t=1}^T l_t, V := \{z_i\},$ $H_i := \sum_{t=1}^T h_{it} : i = 1, \dots, j, \dots, N\}$
<i>Processing</i> \mathcal{F}	$:= \{\alpha, \delta, \zeta, \dots\};$ $\mathcal{K} := \{\tilde{\alpha} x, \tilde{\delta} y, \dots\}$
<i>Semantics</i>	none
<i>Syntax</i>	none

TABLE I
DEFINITION OF SCIP-systemic PROPERTIES.

A. System and Environment

To be able to test the perception-based non-propositional form of language *understanding* realized in SCIP systems, it has to be enacted on natural language discourse whose semantic content is well known and certain in an *externally* defined sense in order to ascertain *internal* divergences from it. This knowledge and certainty is formally guaranteed by inter-subjectively agreeable correct *expressions* of

⁸“Triangle is very far in front, very near to the left. Square is very near in front, extremely near to the right. ...” etc.

$SCIP_{Environment} = \{\mathcal{R}_E, \mathcal{R}_O, \mathcal{R}_G, \mathcal{D}_\oplus, \ell_{\mathcal{R}}\}$	
Plane	$\mathcal{R}_E := \{P_{n,m} : \exists R_{n,m} \in \mathcal{R}_G(n_0, m_0, g), P_{n,m} \in R_{n,m}\}$
Object	$\mathcal{R}_O := \{\square, \triangle, \circ, \dots\}$
Grid	$\mathcal{R}_{G(n_0, m_0, g)} := \{R_{n,m} = [(n-1)g, ng] \times [(m-1)g, mg], 1 \leq n \leq n_0, 1 \leq m \leq m_0, g > 0\}$
Direction	$\mathcal{D}_\oplus := \{\vec{N}=(0,1), \vec{S}=(0,-1), \vec{O}=(1,0), \vec{W}=(-1,0)\}$
Objectlocation	$\ell_{\mathcal{R}} : \mathcal{R}_O \longrightarrow \mathcal{R}_E$

TABLE II

DEFINITION OF SCIP-*environmental* PROPERTIES.

true *propositions* describing a specified segment of *reality*. Controlling this situated process of description are a formal *syntax* and *semantics* employed to generate sentences and texts in pragmatically homogeneous discourse corpora to form the language material. Thus, the non-symbolic form of perception-based processing of these natural language texts (discourse) ideally realizes *understanding* as *symbol grounding* which can be compared to, and tested against the real-world scenario whose *descriptions* are given in the texts processed.

$SCIP_{Coupling}$:	Language entities <i>coupling</i> system and environment <i>structurally</i>
Word:	the sign-object identified as vocabulary element (type) whose occurrences in (linear) sets of sign-objects (tokens) are countable;
Sentence:	the string (non-empty, linear set) of <i>words</i> forming a (syntactically) correct expression of a (semantically) true proposition which denotes a named object's location relative to the system's position (SPOL-relation);
Text:	the string (non-empty, linear set) of <i>sentences</i> with identical (pairs of) core-predicates which describe SPOL-relations resulting from the (mobile) system's linear and step-wise movement relative to (fixed) objects;
Corpus:	the (non-empty) set of <i>texts</i> comprising descriptions of (any/ all/ samples of) factually possible SPOL-relations generated by a systemically and environmentally specified SCIP setting.

TABLE III

DEFINITION OF STRUCTURAL SCIP-*Coupling* ENTITIES.

In order to let this perception-based processing be modeled in terms of information system theory, some conditions have to be specified and defined. They will assure

▷ that the three main components of the experimen-

tal setting, the system, the *environment*, and their *structural coupling* are specified by sets of conditioning properties. These define the SCIP system (Tab. I) by way of a set of procedural entities like *orientation, mobility, perception, processing*. The SCIP *environment* (Tab. II) is defined as a set of formal entities like *plane, objects, grid, direction, location*. And the language discourse material or SCIP-*coupling* (Tab. III) mediating between system and environment is organized by a number of structural properties of embedded part-whole relations like *word, sentence, text, corpus* of which *sentence* and *text* require further linguistic specification to ensure correctness and true descriptions of real world *situations*;

$T(ext) :$	$\{S_i \mid S_i \longrightarrow S_{i+1} : \mathcal{B} \wedge (\{KP_1, KP_2\} \in S_i = \{KP_1, KP_2\} \in S_{i+1}) \wedge \forall KP_j \in S_i \cup S_{i+1}; j = 1, 2; i = 1, \dots, I\}$
$\mathcal{B} :$	$\{g(0,1), g(1,1), g(1,0), g(1,-1), g(0,-1), g(-1,-1), g(-1,0), g(-1,1) : g = 1\}$
$S_i \longrightarrow$	NP VP
NP \longrightarrow	N
VP \longrightarrow	V PP
PP \longrightarrow	HP KP _j
N \longrightarrow	<i>The</i> $\langle triangle \mid square \mid circle \rangle$
V \longrightarrow	<i>is</i>
HP \longrightarrow	$\langle extremely \mid very \mid rather \rangle \langle near \mid far \rangle$
KP ₁ \longrightarrow	$\langle in \text{ front } \mid behind \rangle$
KP ₂ \longrightarrow	$\langle on \text{ the left } \mid on \text{ the right } \rangle$

TABLE IV

TEXT GENERATING PHRASE STRUCTURE SYNTAX.

▷ that the environmental data perceived by the SCIP system consists of a corpus of (natural language) texts whose *correct* expressions of *true* propositions can inter-subjectively be agreed on. This is achieved by introducing a formal text generating *syntax*⁹ (Tab. IV) and a corresponding reference *semantics*¹⁰ (Tab. V) on the base of which sentences and texts may automatically be generated. As *correct* expressions of *true* propositions they describe the environmental situation the system finds itself exposed to, i.e. the object-

⁹The simple *phrase structure grammar* defines texts to consist of sentences whose core predicates are the same.

¹⁰The core predicates' denotations are given according to their symmetric directional dependencies whereas the hedge predicates' (*crisp*) interpretation is numerical which also allows for continuous (*fuzzy*) definitions [3, p. 311].

locations relative to changing system-positions (SPOL-relations). Both, *syntax* and *semantics* represent the formally specified *exo-view* of reality (or the *described situations*). And finally

- ▷ that the system’s internal picture of its surroundings representing the *endo-view* (or *discourse situations*) is to be derived from this textual language environment data other than by way of propositional reconstruction, i.e. without syntactic parsing and semantic interpretation of sentence and text structures. Because this part is the core of the perception-based model of discourse *understanding*, the measurements and processes employed will be dealt with in more detail below.

Core-predicates (KP)

in SPOL relations of system-positions x, y and object-locations n, m (with 0-coordinates down left) for all orientations N, S, E, W of the mobile agent

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

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

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

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

Hedge-predicates (HP)

as distance measure for SPOL-relations (under *crisp* interpretation): in numbers of grid-points $|x-n|$ and $|y-m|$ of a 12×12 grid laid on the reference plane (Fig. 3)

<i>Crisp</i> interpret.	1	2	3	4	5	6	7	8	9	10	11	12
<i>extremely near</i>	1	1	0	0	0	0	0	0	0	0	0	0
<i>very near</i>	0	0	1	1	0	0	0	0	0	0	0	0
<i>rather near</i>	0	0	0	0	1	1	0	0	0	0	0	0
<i>rather far</i>	0	0	0	0	0	0	1	1	0	0	0	0
<i>very far</i>	0	0	0	0	0	0	0	0	1	1	0	0
<i>extremely far</i>	0	0	0	0	0	0	0	0	0	0	1	1

TABLE V

REFERENCE SEMANTICS FOR HEDGED CORE PREDICATES.

B. Scenario and SPOL Relations

With the overall *situation* being a two dimensional reference plane with some stationary objects and a mobile agent (Fig. 3) the SCIP system’s perceptive capabilities are limited to its language processing without (as yet) any other ability to act or react. It is on the grounds of the discourse the SCIP system is exposed to and processes in a sub-symbolic, non-propositional, and perception-based way that the object-locations have to be identified in the reference plane.

The *semioticity* of this processing is conditioned *ex negativo* by the fact that – whatever the system might gather from its language environment – in doing so it will not apply any grammatical knowledge of (symbolically coded) *syntax* or *semantic* rules made available prior to that process. Instead, SCIP is defined to be based solely on the system’s own (co- and contextually restricted) susceptibility and processing capabilities to (re-)cognize, identify, and (re-)organize environmental data structures a *nd* to (re-)present the results in some dynamic structure which determines the system’s *knowledge* (organization), *learning* (change) and *understanding* (representation). It is based on the assumption that a deeper representational level or core structure might be identified as a common base for different notions of meaning developed so far in theories of *referential* and *situational* semantics as well as some *structural* or *stereotype* semantic theories.

The natural language *descriptions*, i.e. the syntactically correct *expressions* of semantically true *propositions* of predications⁸ which represent in their sum a *pragmatically homogeneous text* (PHT) corpus and specify the overall view or the external observer’s *exo-reality* couple the SCIP system and the SCIP environment to each other (as defined by Tabs. I to III). Submitting these *descriptions* to the perception based, sub-symbolic, cognitive processing as defined by DIGS *formalisms* $ref = den \circ des \subseteq T \times X$ is to detect and identify structures and patterns inherent in the *language material* which relate to structures and patterns that organize the *real world* these texts describe as their referential meanings. Due to instantiated and implementable SCIP *algorithms* to process *designation* as $des = par \circ syn \subseteq T \times M$ and *denotation* as $den = env \circ sys \subseteq M \times X$, the detected patterns and structures will result in some mappings and vectorial

representations (*mental images*) in the *semantic space* $p \in M \subseteq I$ constituting its *understanding*. Structures and patterns in semantic space therefore should reveal some of the SCIP system’s internal view of its environment (*endo-reality*) as computed from processing the PHT corpus which describes that environment externally (*exo-reality*).

In order to visualize what structures may be found in the semantic space and visualized accordingly, cluster analyzing algorithms have been employed. They are numerical and independent of any string processing or symbol manipulation techniques common in computational and linguistic semantics, and provide for agglomerative tree structure (*dendrogram*) generation as a means of visualization which is formally controlled, repeatable, and may intersubjectively be agreed upon. Based on such dendrograms another image generating algorithm was developed to allow for a direct comparison and experimental testing of the SCIP system’s capacity to *understand* the referential meanings of language expressions against the externally observed situational reality as specified, described, and represented in the discourse processed.

VI. PROCESS AND MEASUREMENT

Generating language structures and/or analyzing language regularities by computational procedures cannot only be concerned with the application of rules to strings of symbols in order to produce, rewrite, transform, unify, etc. other strings of symbols (sentences), nor is it merely about measuring varying degrees of combinatorial determinacy and to detect different patterns of the language elements’ and structures’ linear distributions. What is important though is to identify computationally these patterns’ and structures’ different types and represent them as (symbolically) labeled possibility distributions of (numerical) values that distinguish and determine (define) these labels¹¹.

A. Syntagmatics and Paradigmatics

Computational processes serving that purpose may therefore be identified with *procedural definitions* of those regularities which they are able to

¹¹It should be noted that the computational processes dealt with here (and below) are not introduced *ad hoc*, but instead were derived from and are embedded in the *semiotically* motivated extension of an information systems theory inspired approach to natural language understanding as part of *dynamic image generating semantics* (DIGS).

detect and analyze as *constraints* and/or to generate and represent as *structures*. Fuzzy linguistics [37] has successfully operationalized some and applied recursively to huge amounts of NL data in PHT corpora. These algorithms detect and analyze language regularities, exploit structures as produced by the constraints concerned [38], and represent these as vectors in possibility spaces from which observable *syntagmata* and *paradigmata* can be derived. Based upon the fundamental distinction of natural language items’ agglomerative or *syntagmatic* and selective or *paradigmatic* relatedness¹², the core of the representational formalism can be characterized as a two-level process of abstraction (Fig. 4). Semiotically these formal constraints $syn \Rightarrow \alpha \mid z_n$ and $par \Rightarrow \delta \mid y_n$ and consecutive mappings $des = par \circ syn \Rightarrow \delta \mid y \circ \alpha \mid z$ model the meanings of words as a function of all differences of all usage regularities (Fig. 5) detected for any vocabulary as employed in a PHT corpus.

A. 1 The first level of constraint exploration or α -abstraction (instantiating the *syn*-relation in Fig. 2) on the set $\{T\}$ of *fuzzy* subsets of the vocabulary $z \in T \subseteq V$ provides the word-types’ usage regularities or *corpus points* $y \in C$.

The basically descriptive statistics used to grasp these relations on the level of *words* in discourse are centered around a correlational measure (Eqn. 4) to specify intensities of co-occurring lexical items in texts, and a measure of similarity (or rather, dissimilarity) (Eqn. 7) to specify these correlational value distributions’ differences. Simultaneously, these measures may also be interpreted semiotically as set theoretical constraints or formal mappings (Eqns. 5 and 8) which instantiate the *designation* morphism $des = par \circ syn \subseteq T \times M$ (Fig. 2 and 5) as a function of differences of usage regularities of words.

For any PHT corpus $K = \{k_t\}; t = 1, \dots, T$ of texts with an overall length

$$L = \sum_{t=1}^T l_t; 1 \leq l_t \leq L \quad (1)$$

¹²According to SAUSSURE [4] universal 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 *constraints* which allow to distinguish not only different levels of entity and structure formation, but also different functions of structure and meaning constitution which structural linguists have learned since to better understand.

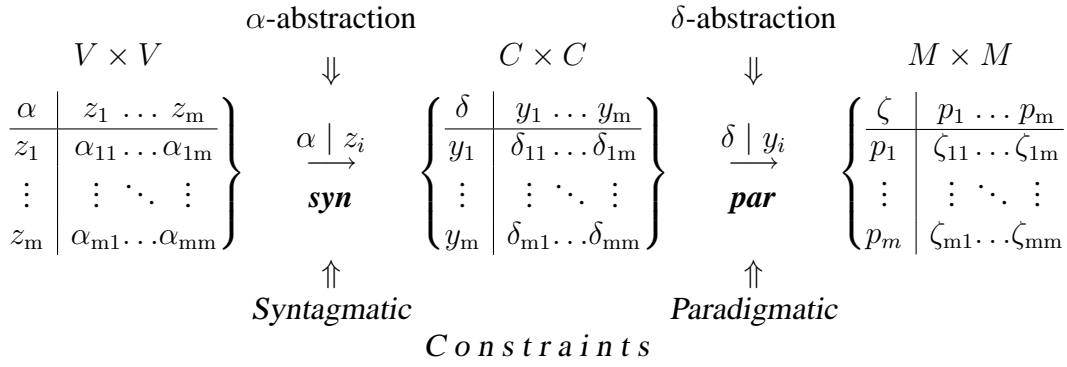


Fig. 4. Formalization of *syntagmatic* and *paradigmatic* constraints as two-level mapping of usage regularities of items $z_i \in V$ and their differences $y_i \in C$. These mappings which are based *first* on the correlation measure $\alpha : V \times V \rightarrow \mathfrak{S}_\alpha$ (Eqn. 4) and *second* on the Euclidian distance $\delta : C \times C \rightarrow \mathfrak{S}_\delta$ (Eqn. 7), constitute consecutive (α - and δ)-abstractions which result in meaning representations $p_i \in M \subseteq I$ respectively.

of word-tokens per text, and a vocabulary

$$V = \{z_n\}; n = 1, \dots, i, j, \dots, N \quad (2)$$

of word-types whose item frequencies are denoted by

$$H_i = \sum_{t=1}^T h_{it}; 0 \leq h_{it} \leq H_i \quad (3)$$

the correlation-coefficient $\alpha_{i,j}$ allows to express pairwise relatedness of word-types $(z_i, z_j) \in V \times V$ in numerical values $\alpha_{i,j} \in \mathfrak{S}_\alpha$ ranging from $-1 \leq \alpha_{i,j} \leq +1$ by calculating co-occurring word-token frequencies in the following way

$$\alpha_{i,j} = \frac{\sum_{t=1}^T (h_{it} - e_{it})(h_{jt} - e_{jt})}{\left(\sum_{t=1}^T (h_{it} - e_{it})^2 \sum_{t=1}^T (h_{jt} - e_{jt})^2 \right)^{\frac{1}{2}}}; \quad (4)$$

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

Evidently, pairs of word types whose tokens frequently either co-occur in, or are both absent from, a number of texts will positively be correlated (*affinity*), those of which only one (and not the other) frequently occurs in a number of texts will negatively be correlated (*repugnancy*).

As a fuzzy binary relation, $\tilde{\alpha} : V \times V \rightarrow \mathfrak{S}_\alpha$ can be conditioned on any $z_i \in V$ which yields a crisp mapping as operational definition of the *syn* morphism (Fig. 2)

$$\text{syn} := \tilde{\alpha} | z_i : V \rightarrow C; C := \{y_i | 1 \leq i \leq N\} \quad (5)$$

where C is the set of *corpus*-points $\{y_n\}$ representing the numerically specified, *syntagmatic* usage regularities that have been observed for any word-type z against all other $z_n \in V$ as measured by

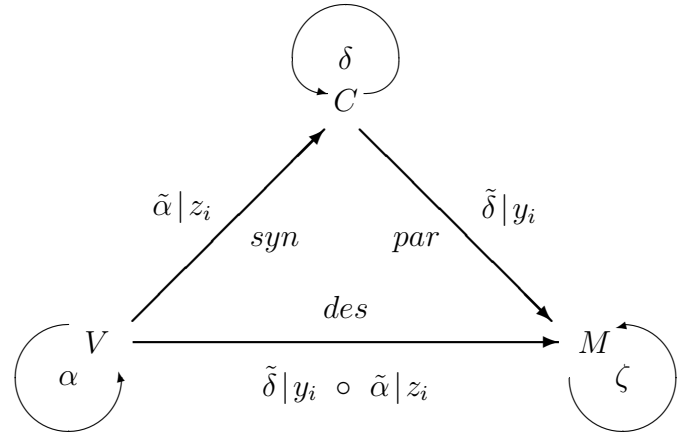


Fig. 5. Fuzzy mapping relations α and δ between the structured sets $\{T\}$ and $\{R\}$ of vocabulary items $z_n \in T \subseteq V$, of corpus points $y_n \in R \subseteq C$, and of meaning points $p_i \in M \subseteq I$ as instantiated reconstruction of the *designation* morphisms *des* in Fig. 2.

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

$$y_i := (\alpha(i, 1), \dots, \alpha(i, N))^N \quad (6)$$

as a point in the N -dimensional *corpus space* $y_i \in C$ spanned by the number of axes N corresponding to the number of vocabulary items (word-types) $z_n \in V$.

A. 2 The second level of constraint exploration or δ -abstraction (instantiating *par* in Fig. 2) on the set $\{R\}$ of *fuzzy* subsets of corpus points $y \in R \subseteq C$ provides the corresponding *meaning points* $p \in M \subseteq I$ as a function (i.e. the set theoretical composition $\text{par} \circ \text{syn}$) of word-types which are being instantiated by word-tokens employed in texts.

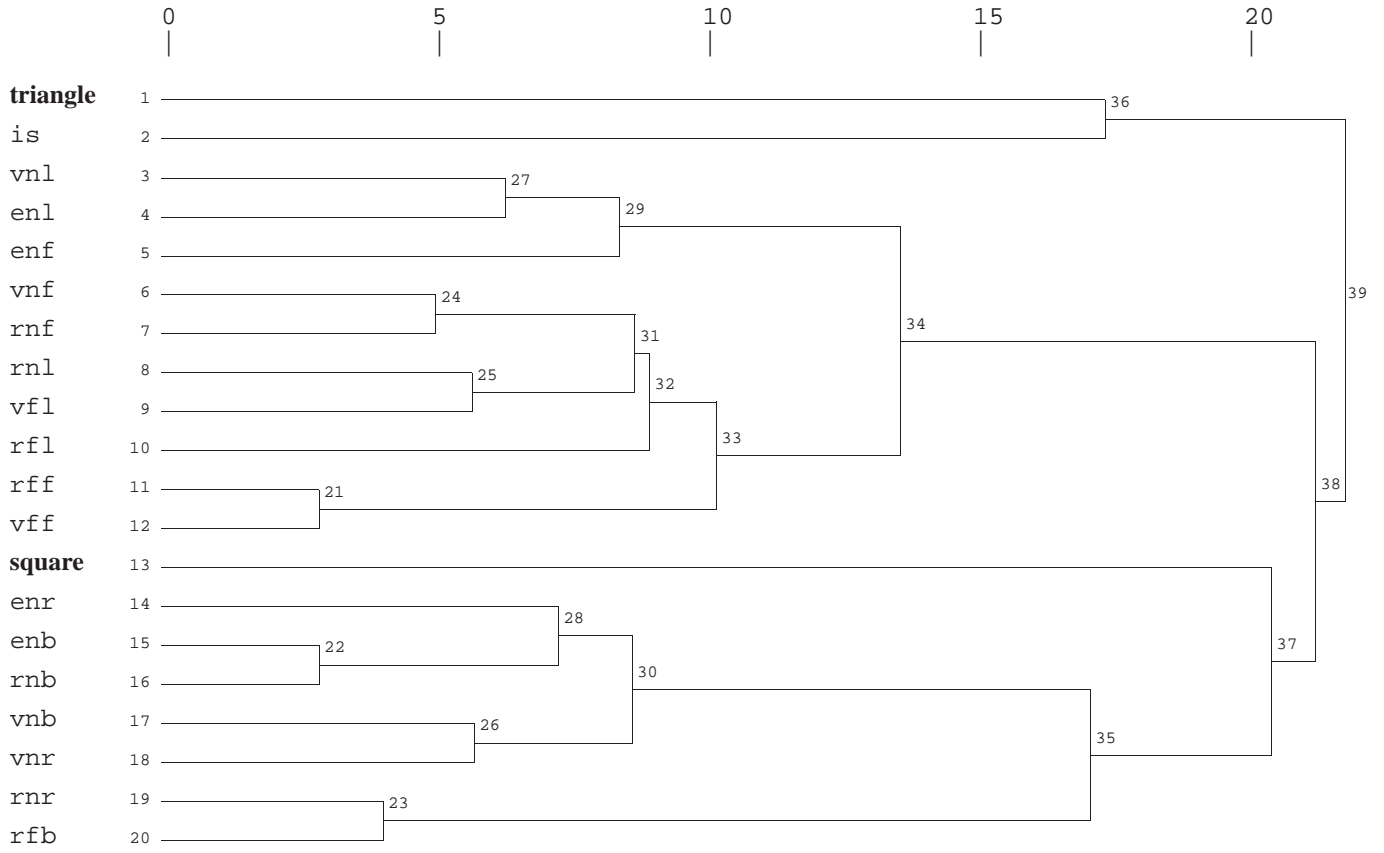


Fig. 6. Cluster dendrogram of labeled meaning points $p \in M \subseteq I$ depicting semantic space structure after processing of 500 texts. Labels of hedge predicates *extremely*, *very*, *rather* (*near* | *far*) and core predicates *left*, *right*, *front*, *behind* are abbreviated to their first letters respectively.

Considering $\langle C, \delta \rangle$ as a representational structure (*corpus space*) of abstract entities constituted by *syntagmatic* regularities of word-token occurrences in *pragmatically homogeneous* discourse, then the similarities and/or dissimilarities of these entities will capture what constitutes their corresponding word-types' *paradigmatic* regularities. These may be calculated by a distance measure δ of, say, EUCLIDIAN metric

$$\delta(y_i, y_j) = \left(\sum_{n=1}^N (\alpha(z_i, z_n) - \alpha(z_j, z_n))^2 \right)^{\frac{1}{2}}; \quad (7)$$

$$\mathfrak{S}_\delta := 0 \leq \delta(y_i, y_j) \leq 2\sqrt{n}$$

Thus, δ may serve as a *second* mapping function to represent any item's differences of usage regularities measured against those of all other items. As a fuzzy binary relation, $\tilde{\delta} : C \times C \rightarrow \mathfrak{S}_\delta$ can be conditioned on $y_i \in C$ which again yields a crisp mapping as

operational definition of the *par* morphism (Fig. 2)

$$par := \tilde{\delta} \mid y_i : C \rightarrow M; \quad M := \{p_i \mid 1 \leq i \leq N\} \quad (8)$$

where M is the set of *meaning-points* $\{p_n\}$ representing the numerically specified *paradigmatic* structure that has been derived for each abstract *syntagmatic* usage regularity y_i against all other $y_n \in C$. The distance values can therefore be abstracted analogous to Eqn. 6, this time, however, over the other of the two components in each ordered pair, thus defining an element

$$p_i := (\delta(i, 1), \dots, \delta(i, N))^N \quad (9)$$

called *meaning point* $p_i \in M \subset I$ in a N-dimensional structure called *semantic space*.

Thus, the perception-based, non-symbolic, numerical processing of the PHT corpus of natural language expressions describing real world situations yields vectorial representations of meaning points in *semantic space* whose structuredness is obvious

determinate *exo*-view representation¹³ (Fig. 8). This can subsequently be transformed into another format to visualize

- 4) the referential plane as structured holistically by a profile of (numerically interpolated) polygons which connect regions of denotational likelihood by so-called *isoreferentials*; their emerging overall pattern denotes possible object locations (Fig. 9).

B. 1 Earlier investigations into the intrinsic structure of *semantic space* data had revealed [43, 45] that topological adjacencies of meaning points can well be identified, and clusters of points be detected and represented in an agglomerative process with an average linkage cluster criterion. Applying these techniques to the semantic space structure as presently computed from processing PHT corpora of increasing size (50 to 500 texts) resulted in dendrograms like Fig. 6. It clearly separates the collections of core predicate labels (34):*front-left* from (35):*behind-right* and identifies the latter as (37):*square*. The former is – in conjunction with the copula (36):*is* – less distinct as (39):*triangle* comprises all labels.

B. 2 As the semantic space structure may be considered the internal model (*endo-view*) of what the SCIP system gathered in processing the language data it was exposed to, this structure has to be transformed in order to be visualized to allow for a comparison with real world situation (*exo-view*) described according to an externally defined grammar (*syntax* and *semantics*). For this transformation the four hedged core predicates (*left*, *right*, *front*, *behind*) are employed to determine a 2-dimensional 23×23 grid (Fig. 7) which spans from the oriented system's center position into four directions along the concentric frames (*extremely*, *very*, *rather*, *very*, *extremely*) of hedged *near* and *far* regions. The numbers at each point i, j – that make the grid the $Endo1_{i,j}$ transformed data representation – are frequencies as provided by the cluster dendrogram which allows to identify each hedged core predicate

¹³As the experimental setting does not (yet) allow the mobile system's *orientation* to change while traversing the reference plane in different *directions*, the predicates employed during generation of SPOL-relation descriptions are confined to be directionally determinate (*in front=north*, *left=west*, etc.). To allow changing orientations for the mobile system would necessitate a procedural modeling and algorithmic reconstruction of less restricted *environmental* and *systemic* constraints $env \circ sys$ which (so far) have been assumed part of the *structural coupling*.

with the number of agglomerative steps it is part of.

B. 3 The $Endo1_{i,j}$ data (Fig. 7) serves as base for this third step which is a line- and column-wise data compression transformation. It results in a new mapping $Endo2_{m,n}$ (Fig. 8) according to the summation equation

$$Endo2_{m,n} = \sum_{i=m}^{m+11} \sum_{j=n}^{n+11} Endo1_{i,j} \quad (10)$$

B. 4 The matrix $Endo2_{m,n}$ (Fig. 8) represents the data structure transformed for an external *observer's* visualization of the system's *endo-view* as processed from texts describing SPOL-relations, i.e. fixed object locations relative to changing system positions. The corresponding (two-dimensional) images generated on the base of $Endo2$ -increments of text corpora of increasing size (50 to 500 texts) gives an impression of the dynamics of the developing picture of referential likelihood (Fig. 9). The polygons interpolating the $Endo2_{m,n}$ data points are called *isoreferentials* whose overall pattern forms a profile that denotes potential object locations quite clearly as regional maxima, however *fuzzy*.

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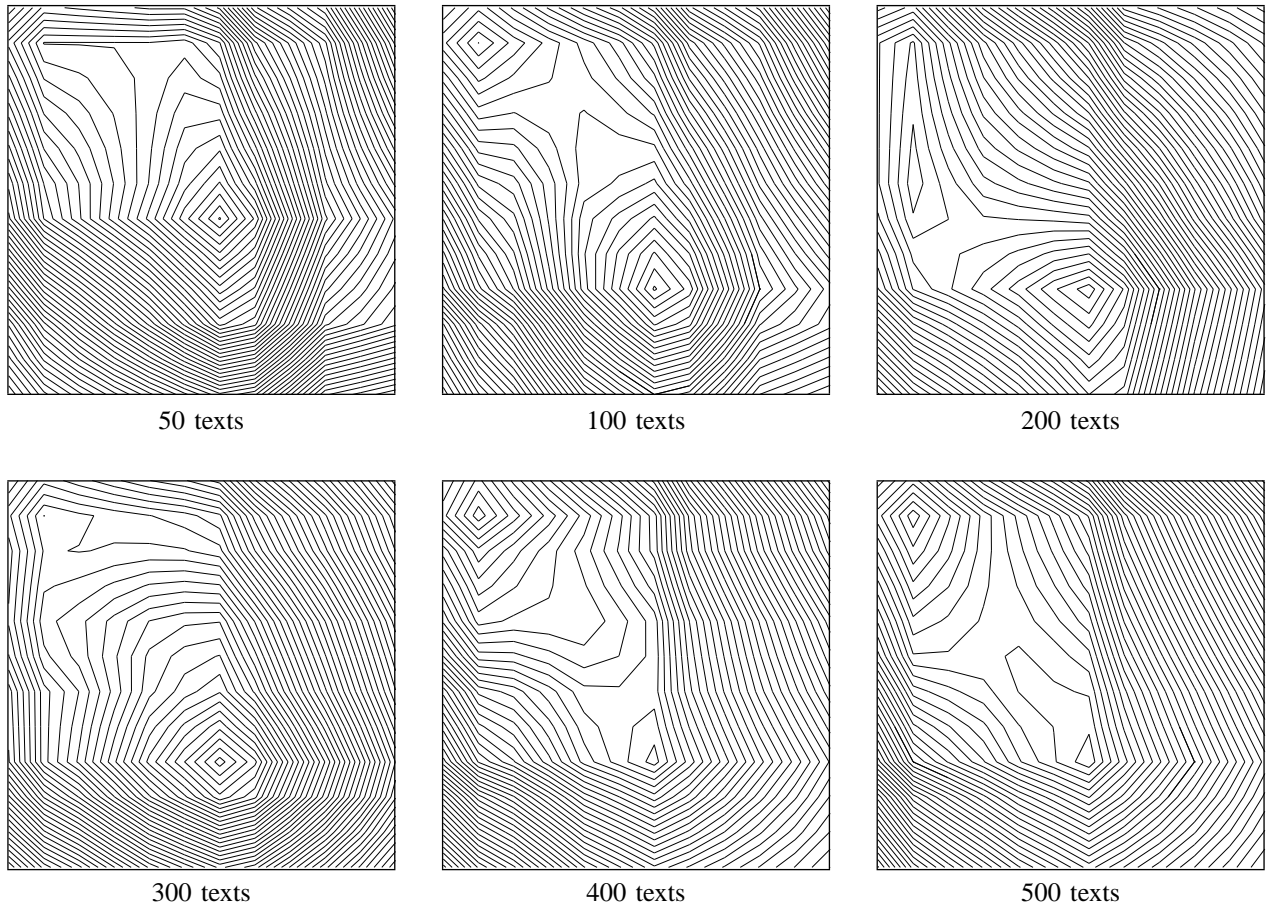


Fig. 9. 2-dim visualizations of potential object locations (*isoreferentials*) depicting the SCIP system's incremental *meaning constitution* or *learning* to understand (without any knowledge of *grammar*) by sub-symbolic, perceptual processing of textual constraints in an increasing number of (50 to 500) texts. Thus, the SCIP language understanding capacity is tested against real world situations which these texts refer to. The *situations* are created by the mobile agent's random walk producing changing system positions relative to stationary object locations (SPOL-relations) in a 2-dim *reality* (Fig. 3), and their *descriptions* in NL texts of simple, declarative sentences⁸ are generated in a grammatically well defined way controlled by formal *syntax* (Tab. IV) and referential *semantics* (Tab. V).

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