On Simulation and Realization.

Procedural models of sign functions in computational semiotics.

Burghard B. Rieger

Dept. of Computational Linguistics – Fachbereich II: LDV/CL
University of Trier, D-5428 TRIER, Germany
E-Mail: `rieger@ldv.Uni-Trier.de`

Abstract

1 Introduction

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

From the model constructor's position it has been outlined [3] that apparently the matter-symbol, or the material-sign, or the structure-function distinctions are difficult to determine in (primitive) organisms' behavior, quite contrary to the sharp distinctions which are drawn in (models of) dynamic physical behavior. This is due to the fact that only from the modeler's (external) view the organisms' processing of environmental information appears to be based upon principled structures (*representations*) of processing results whereas an organism's own (internal) processing may in fact do very well without such representational structures and apparently survives on merely performing some sorting procedures or classification functions allowing to identify the relevant (and to ignore the irrelevant) components in its surroundings, possibly—but not necessarily—based on prior experience in similar situations. Therefore, relating *structure* to *function* may well be considered but another aspect of how the notion of representation (internal or external to a system) can be *realized* instead of *simulated* in a system-environment model of cognitive information processing.

> First, *simulations* and *realizations* belong to different categories of modeling. Simulations are metaphorical models that symbolically "stand for" something else. Realizations are literal, material models that implement functions. Therefore, accuracy in a simulation need have no relation to quality of function in a realization. Secondly, the criteria for good simulations and realizations of a system depend on our theory of the system. The criteria for good theories depend on more than mimicry, e.g. Turing Tests. Lastly, our theory of living systems must include evolvability. Evolution requires the distinction between symbolic genotypes [*types* of language entities], material phenotypes [*tokens* of language entities], and selective environments [*situations* of communicative language use]. Each of these categories has characteristic properties that must be represented in artificial life (AL) models.[1]

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

2 Computational Semiotics

Computational Semiotics is inspired by *information systems theory* according to which human beings may be taken as living *systems* whose knowledge based processing of represented *information* makes them *cognitive*, and whose sign and symbol generation, manipulation, and understanding capabilities render them *semiotic*. We all experience these systems' performance and ability daily in performing cognitive processes and representing their results, in organizing these representations and activating them for situations in need of augmenting information, in acting on the base of these activated representations, and in modifying them according to changing conditions, results, and states of system-environment adaptedness. It is argued that human cognition is grounded in such complex information processing. Whenever cognitive processes are modeled as being based upon structures whose representational status is not a presupposition to but a result from such processing, then these models—being able to simultaneously initiate and modify the structures they are operating on—may qualify as being part of *computational semiotics*.

3 Natural Language Understanding

For cognitive models of natural language processing the systems theoretical view suggests to accept natural language discourse as analyzable and empirically accessible evidence for tracing such processes. Thus, natural language discourse might reveal essential parts of the particularly structured, multi-layered information representation and processing *potential* to a system analyzer and model constructor in rather the same way as this potential is accessible to an information processing system trying to understand these texts. The difference here, however, between the system and its analyzer on the one hand, and the information system engaged in processing its discourse environment on the other, is that of an object-modeler relation vs. a system-environment situation, i.e. being active in and part of different information processing *situations* of which only the latter—and not the former—can be said to be directly accessible to the modeler via attunement. It is this lack of being properly *attuned* to the *semiotic* principles underlying understanding systems in general which prompts cognitive linguists to fall back on situations they are attuned to, namely natural language understanding whose formal abstractions they believe to be provided by principled *internal language* (IL) representations of language *competence*[2]. But whereas in communicative language understanding one can, and even has to take the *semiotics* of signs and the constitution of meanings for granted and beyond questioning (i.e. signs and meanings are meant to be understood, no matter whether fully or only partially, whether correctly or even wrongly), the purpose of modeling that very process of meaning constitution or *understanding* must not. Trying to understand (conditions of possible) understanding of signs and meanings cannot rely on the *simulative* processing of (symbol) structures whose representational status is declared by drawing on a pre-established semantics (known by the modeler, made accessible to the model, but not at all compulsory for the system modeled). Instead, modeling the processes contributing to meaning constitution or *understanding* will have to *realize* that very function. It has to be implemented as programmable algorithms in an operational information processing system which is able to render some structure—in a self-organizing way—representational of something else, and which also allows to identify what that structure is to stand for. This is—very briefly—what establishes a *symbol* or sign-meaning relation whose *semantics* is a way of representing this relation in an overt and intelligible sense to other (natural and/or artificial) *semiotic cognitive information processing* (SCIP) systems. The notions of *discourse situation* and of *language game* will serve to mediate the dynamics of *semiosis* and the procedural approach to model SCIP systems as based upon natural language discourse.

4 Information Systems View

Following the systems theoretical paradigm of information processing and accepting the cognitive point-of-view according to which any information processing is knowledge based, human beings appear to be not just natural information processing systems with higher cognitive abilities. Instead, they have to be considered very particular cognitive systems whose outstanding plasticity and capability to adapt to changing environmental conditions is essentially tied to their use and understanding of natural languages in communicative discourse. The basic idea of model constructions in terms of such an ecological theory of information systems [10] is that the processing structure of an information system is a correlate of those structures which such a system is able to process in order to survive. Consequently, analyzing the complex structuredness of natural language discourse as a computational process of structure formation and detection is not only following from cognitive science's computability assumption, but may also give some hints for procedural models and computational properties of processes that underlie (or contribute to) language *understanding*.

4.1 Modes of Representation

In the aggregated form of *pragmatically homogeneous text* (PHT) corpora [5], communicatively performative natural language discourse provides a cognitively revealing and empirically accessible collection of traces of processes whose resultant multi-faceted structuredness may serve as guideline for the cognitively motivated, empirically based, and computationally realized research in *meaning constitution* [11].

In terms of the theory of information systems, such PHT corpora function like virtual environments. Considering the system-environment relation, *virtuality* may be characterized by the fact that it dispenses with the identity of space-time coordinates for system-environment pairs which normally prevails for this relation when qualified to be indexed *real*. It appears, that this dispensation of 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. Accordingly, *immediate* or adaptive space-time-identical system-environments without representational form may well be distinguished from

mediate or learning space-time-dispensed system-environments whose particular representational import (*texts*) corresponds to their particular bivalent timely status both, as longer-term material (composed of language *signs* having virtual *meaning*), and as short-term structure (in need of being *(re)cognized* in order to be *understood*). This double identity calls for a particular modus of actualization (*understanding*) that may be characterized as follows:
For systems appropriately adapted and tuned to such virtual environments, *actualization* consists essentially in a twofold embedding to realize

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

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

4.2 Semiotic Enactment

Semiotic systems' ability to actualize environmental *representations* does not merely add to the amount of experiential results available, but constitutes also a significant change of experiential modus. This change is characterized by the fact that *processes* of experience may be realized ("learning how") as being different and hence be separable from the *results* of that experience ("learning what"). Whereas in *immediate* system-environment situations, processes without traceable representations appear to be indistinguishable from their results ("adaptation"), *mediate* system-environments are constituted by this very distinction.

In modeling *semiotic cognitive information processing* (SCIP) systems' performances, the concept of *representation* has to be considered fundamental to the computational semiotic approach to cognition, allowing to realize—instead of simulating—the experiential distinction of semiotic *processes* of cognition from their *results* which emerge—due to the traces these processes leave behind—in some structures (*knowledge*). Different representational modes of this structure [14] not only comply with the distinction of *internal* or *tacit* knowledge (as e.g. in modeling *memory*) on the one hand and of *external* or *declarative* knowledge (as e.g. in representations of *discourse*) on the other[2],

[2] Whereas *tacit knowledge* cannot be represented other than by the *immediate* system-

these modes also relate to different types of (*distributional* vs. *symbolic*) formats, (*connectionist* vs. *rule-based*) modeling, and (*stochastic* vs. *deterministic*) processing.

5 Modeling Semiotic Realizations

Information processing situations (comprising *system, environment*, and *processing*) are considered *cognitive* inasmuch as the system's internal (formal and procedural) knowledge has to be applied to identify and recognize structures external to the system (*meaning interpretation*). These situations become *semiotic* whenever the internal knowledge applied to identify and interpret environmental structures is derived from former processes of external structure identification and interpretation, and applied as the result of self-organizing feedback through different levels of (inter-)mediate representation and organization. This process (of *meaning* constitution or structure *understanding*) is the multiple enactment of the threefold relation which is called—following Peirce—*semiosis*[3].

The triadic relation allows for the different ontological abstractions of *language*

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

5.1 Semiotic Attunement

In a systems theoretic approach, *attunement* replaces the notion of *static* knowledge structures as simulated in cognitive information processing models so far, by a *dynamic* conception of structuredness. It defines knowledge as an open, modifiable, and adaptive system whose organization can be conceived as a function of the system's own processing or *knowledge acquisition*. This, however, can only be achieved by allowing *semiotic entities* to have their own (perhaps yet unknown) ontology. It might be not (or not fully) accounted for[4] by predicative and propositional representations or rule-based and truth-functional formats which tacitly make believe that semiotic entities can be

environments' corresponding states ("knowledge how", *explicit knowledge* is bound to acquire some formal properties in order to become externally presented and thereby part of *mediate* system-environments ("knowledge what"). Natural languages obviously provide these formal properties—as partly identified by research in linguistic competence (principled knowledge and acquisition of language)—whose enactment—as investigated in studies on natural language performance (production and understanding of texts)—draws cognitively on both bases of (explicit and tacit) knowledge.

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

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

characterized and their functions be modeled exclusively by crisp categorial structures and associated processing of well-defined rules for symbol manipulation.

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

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

Representing a system's environment (or fragments thereof) in a way, that such representations not only take part in a system's direct (*immediate*) environment (via language texts) but may moreover be understood as virtual in the sense that new (*mediate*) environments (via textual meanings) can also be processed, has been explicitly introduced elsewhere [15] [8] [9]. This view is again dependent on how a system's attunement to these kinds of situated discourse can be tied to the formal concept of *situation* [1] and the analytical notion of *language game* [16] phenomenologically (re)interpreted. The combination of both lends itself readily to operational extensions in empirical analyses and procedural simulations of processes which may grasp essential parts of meaning constitution realized as process of *understanding*.

5.2 Situated Semantics

According to Barwise and Perry [1] any language expression is tied to reality in two ways: by the *discourse situation* allowing an expression's meaning being *interpreted* and by the *described situation* allowing its interpretation being *evaluated* truth-functionally. Within this relational model of *Situation Semantics meaning* may be considered the derivative of information processing which (natural or artificial) systems—due to their own structuredness—perform by recognizing similarities or invariants between situations that structure their surrounding realities (or fragments thereof).

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

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

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

5.3 Language Games

According to Wittgenstein [16] the notion of *language game*[5] characterizes a very fundamental type of discourse situations "complete in themselves, as *complete systems* of human communication" and solely concerned with the way of how signs are used. Operationalizing this notion and analyzing a great number of texts for *usage regularities* of terms can reveal essential parts of the concepts and hence the meanings conveyed by them. The approach [6] has also produced some evidence that an analytical procedure appropriately chosen could well be identified also with solving fundamental representational tasks if based upon the universal constraints (*syntagmatics* and *paradigmatics*) known to be valid for all natural languages.

This philosophical concept of *language game* can be combined with the formal notion of *situation* allowing not only for the identification of a cognitive system's (*internal*) structure with the (*external*) structure of that system's environment. Being tied to the observables of actual language performance enacted by communicative lan-

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

guage usage also opens up an empirical approach to procedural semantics and *computational semiotics*. Whatever can formally be analyzed as *uniformities* in BARWISEian *discourse situations* may eventually be specified by word-type regularities as determined by co-occurring word tokens in samples of pragmatically homogeneous texts as representations of *language games*. Going back to the fundamentals of structuralistic descriptions of regularities of *syntagmatic* linearity and *paradigmatic* selectivity of language items, the correlational analyses of discourse will allow for a multi-level word meaning and world knowledge representation whose dynamism is a direct function of elastic constraints established and/or modified in language communication.

6 Conclusion

1. As has been outlined in some detail elsewhere [14], the meaning function's range may be computed and realized as a result of exactly those (semiotic) procedures by way of which (representational) structures emerge and their (interpreting) actualization is produced from observing and analyzing the domain's regular constraints as imposed on the linear ordering (*syntagmatics*) and the selective combination (*paradigmatics*) of natural language items in communicative language performance. For natural language semantics this is tantamount to (re)presenting a term's meaning potential by a fuzzy *distributional pattern* of the modeled system's state changes—rather than by a *single symbol*—whose structural relations are to depict the system's potential interpretations of its environment. Whereas symbolic representations have to *exclude*, the distributional representations will automatically *include* the (linguistically) structured, pragmatic components which a SCIP system will both, embody and employ as its representational and procedural import to identify and to interpret its environmental structures by means of its own structuredness.

2. In earlier attempts, *semantic* meaning functions have been modeled and computed as results of the same (semiotic) procedures by way of which (representational) structures emerge [15]. Their actualization (interpretation) can be simulated by analyzing the possibilistically determined constraints found as imposed on the linear ordering (*syntagmatics*) and the selective combination (*paradigmatics*) of natural language entities (word-types) in discourse [7]. For *fuzzy linguistic* lexical semantics this is tantamount to (re-)construct an entity's *semiotic* potential (meaning function) by a weighted graph (fuzzy *distributional pattern*) representing the modeled system's state space rather than by a *single symbol* whose interpretation has to be arbitrary [11]. In this view the emergence of semantic structure can be represented and studied as a self-organizing process based upon word usage regularities in natural language discourse [8]. In its course, the linearly agglomerative (or *syntagmatic*) as well as the distributionally selective (or *paradigmatic*) constraints are exploited by text analyzing algorithms [9]. These accept natural language text corpora as *input* and produce—via levels of intermediate representation and processing—a vector space structure as *output*. As *semantic hyperspace (SHS)* it may be interpreted as an internal (*endo*) representation of the SCIP system's states of adaptation to the external (*exo*) structures of its environment as mediated by the discourse processed [10]. The degree of correspondence between these two is determined by the granularity that the texts provide in depicting an *exo*-view, and the resolution that the SCIP system is able to acquire as its *endo*-view in the course of that discourse's processing [12].

3. The SCIP system's architecture is a two-level consecutive mapping of distributed representations of systems of (fuzzy) linguistic entities. Being derived from usage regularities as observed in texts, these representations provide for the aspect driven generation of formal dependencies and their interrelations in a format of structured stereotypes. Corresponding algorithms select and represent fuzzy subsets (word meanings) as dispositional hierarchies that render only those relations accessible to perspective processing which can—under differing aspects differently—be considered relevant. Such dynamic dispositional dependency structures (*DDS*) have proved to be an operational prerequisite to and a promising candidate for the simulation of content-driven (analogically-associative) reasoning instead of formal (logically-deductive) inferences in semantic processing [13].

4. The dynamics of *semiotic* knowledge structures and the processes operating on them essentially consist in their recursively applied mappings of multilevel representations resulting in a multiresolutional granularity of fuzzy word meanings which emerge from and are modified by such text processing. Test results from experimental settings (in semantically different discourse environments) 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.

References

[1] J. Barwise/J. Perry: *Situations and Attitudes*, Cambridge, MA (MIT Press), 1983.

[2] N. Chomsky: *The Minimalist Program.* (Current Studies in Linguistics 28), Cambridge, MA (MIT Press), 1995.

[3] H. Pattee: Evolving self-reference: matter, symbol, and semantic closure. *Communication and Cognition – Artificial Intelligence*, 12(1-2): 9–27, 1995.

[4] C. Peirce: Pragmatism in Retrospect: A Last Formulation. In: Buchler (ed): *The Philosophical Writings of Peirce*, New York (Dover), 1906, pp. 269–289.

[5] B. Rieger: Bedeutungskonstitution. Einige Bemerkungen zur semiotischen Problematik eines linguistischen Problems. *Zeitschrift für Literaturwissenschaft und Linguistik*, 7(27/28): 55–68, 1977.

[6] B. Rieger: *Unscharfe Semantik. Die empirische Analyse, quantitative Beschreibung, formale Repräsentation und prozedurale Modellierung vager Wortbedeutungen in Texten*, Frankfurt/ Bern/ Paris (Peter Lang), 1989.

[7] B. B. Rieger: Fuzzy Computational Semantics. In: Zimmermann (ed): *Fuzzy Systems. Proceedings of the Japanese-German-Center Symposium*, Series 3: Publications of the Japanese-German Center Berlin 8, Berlin (JGCB), 1994, pp. 197–217.

[8] B. B. Rieger: Meaning Acquisition by SCIPS. In: Ayyub (ed): *ISUMA-NAFIPS-95*, IEEE-Transactions: 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.

[9] 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.

[10] B. B. Rieger: Situation Semantics and Computational Linguistics: towards Informational Ecology. A semiotic perspective for cognitive information processing systems. In: Kornwachs/Jacoby (eds): *Information. New Questions to a Multidisciplinary Concept*, Berlin (Akademie), 1996, pp. 285–315.

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

[12] B. B. Rieger: Dynamic Word Meaning Representations and the Notion Granularity. Text understanding as meaning consitition by SCIPS. In: Meystel (ed): *A Learning Perspective: Proceedings of the 1997 International Conference on Intelligent Systems and Semiotics (ISAS-97)*, [NIST Special Publication 918], National Institute of Standards and Technology, Washington, DC (US Gov. Printing Office), 1997, pp. 332–333.

[13] B. B. Rieger: Tree-like Dispositional Dependency Structures for non-propositional Semantic Inferencing. On a SCIP approach to natural language understanding by machine. In: Bouchon-Meunier/Yager (eds): *Proceedings of the 7th International Conference on Information Processing and Management of Uncertainty in Knowledge-based Systems (IPMU-98)*, Paris (Edition EKD), 1998, pp. 351–358.

[14] B. B. Rieger: Computating Granular Word Meanings. A fuzzy linguistic approach in Computational Semiotics. In: Wang/Meystel (eds): *Computing with Words*, New York, NY (John Wiley), 1999, p. [in print].

[15] B. B. Rieger/C. Thiopoulos: Semiotic Dynamics: a self-organizing lexical system in hypertext. In: Köhler/Rieger (eds): *Contributions to Quantitative Linguistics. Proceedings of the 1st Quantitative Linguistics Conference – QUALICO-91*, Dordrecht (Kluwer Academic Publishers), 1993, pp. 67–78.

[16] L. Wittgenstein: *The Blue and Brown Books. (Ed. by R. Rhees)*, Oxford (Blackwell), 1958.