5th Slovakian-Hungarian Joint Symposium on Applied Machine Intelligence and Informatics
January 25-26, 2007 ░ Poprad, Slovakia

Neuro-Fuzzy Approaches to Natural Language Data Processing

Ulrich H. Langanke

Budapest Tech
Bécsi út 96/B, H-1034 Budapest, Hungary
langanke.ulrichgk.bmf.hu

Abstract: Dubbed the 'age of permissiveness' by traditional mathematicians, philosophers and linguists, the period since the late 1960ies has marked a fundamental change in the estimation of logical exactness of the type 'A or not-A'. Since then, the realm of Aristotle, the cultural exclusiveness of binary logic, has been seriously challenged by Fuzzy Logic. Fuzzy sets, vagueness, multivalence and multivalued categories of the type 'A and not-A', have caused paradigm shifts in those technical sciences focussing on the simulation of the human neural network, e. g. cognitive sciences, artificial intelligence, informatics, mechatronics, automation and language processing. However, they do not seem to be equivalently considered in product oriented linguistics, despite some theoretical efforts in cognitive linguistics. Regardless of typological differences such as print-based or electronic, even recently released dictionaries, maps/atlases exploring data on language diversity, language learning programmes or language processing are caught in the 'memetic' trap of bivalence. This essay reveals the interdisciplinary methodological interdependence between the three levels of 1) programming and language processing, 2) the linguistic data set as a continuum and 3) the design/presentation of fully fuzzified electronic language data sets based on the combined principle of Neuro-Fuzzy systems.

Keywords: autosemantic, bivalent logic, continuum linguistics, differentiae specificae, genus proximum, LAD (Language Acquisition Device), language diversity, meme, memetics, multivalence, structuralism, test-score semantics, truth-functional

1 'A or not-A' – Aristotle's Methodological Trap

Logic is binary, Aristotle's 'genus proximum' and 'differentiae specificae' still hold as memetic[1] figures in western reasoning and categorizing. Although

[1] Memetics is a multidisciplinary scientific approach between neurosciences, genetics and sociology/philosophy, trying to analyse the effect of soft factors like culture and tradition on evolution and evolutionary changes. Memetics decribes this interdependence as caused by so-called 'memes', social genes as the essential factor for social selection and therefore in the role of a catalyst for genetic reproduction. Concrete examples for such memetic

philosophers as well a mathematicians have always dealt with randomness, probability, uncertainty or vagueness, it was the Buddhism-inspired Fuzzy Logic that, for the first time, embraced the imprecision of real-world phenomena and accepted vagueness as natural instead of employing ever more analytic approaches. Fuzzy sets have soon begun to play an essential role in mathematics, informatics, artificial intelligence and even semantics. Also widely applicated in industry, e. g. automatisation, autoadaptive systems and controlling, they have led to a fundamental change in the estimation of logical truth of the type 'A or not-A'. The terms 'fuzzy'/'fuzziness' stand for vague/vagueness or gray/grayness, the philosophy behind states that everything is a matter of degree (Kosko 1994, Zadeh 1965, 1968, 1978, 1981). Fuzzy Logic was introduced into science by Lotfi Zadeh in 1965, differing from other theories such as logical positivism, predicate logic, probability or bivalence, however keeping the potential to integrate their results as extreme forms of grayness (the numeric values 0 and 1 are extreme forms of the continuum between 0 and 1, a linguistic example would be: *antique* vs. *modern* are just different degrees within this continuum as e. g. a Jaguar E-Type is a car which is to some degree antique (compared to the most recent formula 1 racing car) and to some degree modern (compared to an ancient roman vehicle).

However, beyond some efforts in cognitive linguistics such as Stereotype and Prototype semantics no serious attempts have been made to confront linguistic paradigms or subsets with the crucial idea of fuzziness. This is nothing but astonishing, as among all other disciplines within human sciences, linguistics seems to be most drastically exposed to paradigm shifts provoked by advances in artificial intelligence and other sciences treating with electronic data processing. An analysis of hypermedia language products or applications of language processing/simulation shows that none of the three components 1) programming and language processing, 2) the linguistic data set as a continuum and 3) the design/presentation has been methodologically revised according to fuzzy overlap truth of the type 'A and not-A'. Thus, theory, methodology or even linguistically determined products such as translation programmes, language processing devices, natural language-based computer systems, hypermedia realisations or online-products stay rather conventional, dominated by bivalence-accustomed paradigms, digitally programmed and, consequently, not matching with the fuzzy real-world aspects of human language such as language diversity with its manyfold subsets. Neuro-Fuzzy systems provide the most plausible and therefore most real-world-based interpretation of a possible modelling of natural language or its subsets.

The specific relational structure of meaning (as in linguistic semantics) allows the idea of fuzzy sets, vagueness and multivalence to be applied and implemented in semantic concepts, finally replacing referential semantic theorems. Even one of

---

complexes are natural language, dialects (as part of language diversity), theories, science, religion, moral, etc. (Aunger 2000, Blackmoore 2000) the first systems of this kind, Zadeh's PRUF (1978), has used a meaning representation language for natural languages which is possibilistic instead of truth-functional. There, the so-called 'dictionary' provides linguistically determined fuzzy subsets of real-world phenomena rather than bivalent sets of semantic markers under word-headings. Here we have the crucial point, as semantic and other markers (stilistic, pragmatic, regional, diatopic, etc.) are the traditional linguistic means of dealing with vague entities, unsharp categories and continuum patterns within language diversity. However, the basic idea of a fuzzification of referential concepts can be explicated as a vague correspondence between natural language terms and a universe of discourse/context. As for algebraic application, this correspondence is characterized by a memebership-function, the grade of membership being a numeric value between 0 and 1.

2 Traditional Approaches to Language Modelling – Finite-State Devices and Binary Logic

My multidisciplinary approach to electronic data processing of natural languages with special regard to subsets of language diverity focusses on solutions beyond the traditional binary logic still dominating analytic theorems. Not even the most sophisticated and complex approaches within binary or predicate logic, neither in neural sciences, nor in artificial intelligence, cognitive sciences or even linguistics have yet delivered the final description of the specific character of human language. Although inconsequent as being put down to analytic concepts, the reduction of the phenomenon natural language to selected, linguistically defined subsystems seems necessary in the beginning. This helps us in two ways, 1) avoiding general, plausible yet non-proven philosophical statements on natural language and 2) hinting at the particular difficulties when simulating natural languages or aspects of them within the traditional, binary finite-state methods/finite automata. Usually provided, is a limited set of representative inputs that were successfully processed at a certain state of development of the system, together with a mostly bivalent description of the set of rules of their processing in form of algorithms. We will later see, that the proposed modelling of vague aspects of natural language diversity with Neuro-Fuzzy systems partially follows the same path, as (artificial) neural networks, the first constituent, can learn from given data sets but cannot be interpreted, whereas fuzzy systems consist of linguistic rules, therefore they are exposed to interpretation, however, the fuzzy system itself does not learn. Despite all efforts, language diversity and its various subsystems, comprising dialectal aspects, sociolinguistic markers, diasituative differences or registers and the problem of meaning in semantics have continuously inhibited scientists from a precise linguisitc analysis of natural language and, as a consequence, a precise and reliable real-world (electronic) modelling of languages.

Finite-state devices are used as a core technology in many fields of natural language processing. The available applications include speech recognition and generation, spelling correction, question-answering and programming systems, information retrieval and improvements in translation. Despite promising results, traditional approaches on language modelling seem to be in a double trap. A successful modelling with rule description may lead to the fatal conclusion, that natural languages could be exhaustivly and exclusively qualified and therefore interpreted as rule-based systems or, even more misleading, as only one rule-based system, as generative grammar with its phylogenetic LAD (Language Acquisition Device) has supposed. That is to state, that all aspects of any natural language could be non-ambigously put down to a set of rules, if not mathematical equations. Several linguists such as Chomsky or Wittgenstein have reasoned on this problem, and the so-called 'Chomsky grammars' are still a commonly operated means in electronic simulation of human language.

Doubtlessly, it has been proven, that essential aspects of natural languages can indeed be processed with finite automata, additionally providing several advantages for mass data processing in general, which is an essential pre-condition of succsessful language modelling. Two of the most decisive are: firstly, the framework given allows for a uniform processing of information described by sets of rules and enables the system to operate the above mentioned vague, ambigue, unprecise linguistic data, concerning e. g. language diversity, that would have to be specifically lexicalized, although weighted automata are in general suitable for variable data. Secondly, finite automata provide a fast and secure data handling, their algebraic foundation, based on theorems of binary logic and its digitalization, is easily understood and permits modular architecture together with automatic compilation of specific system components.

As already mentioned, the partially successful description and therefore possible simulation of natural language as a rule-based system within finite-state devices may lead to several misunderstandings and misinterpretations of the manyfold interdependences between artificial intelligence and linguistics, on the one hand profiting from each other but also caught in the respective methodologic trap. Important linguistic approaches still differ in weighting the influence and functional role of language components such as phonetics, morphology, lexic, semantic, syntax, whereas the standard level of modelling natural language with finite automata focusses on three levels: lexical analyis, semantic analysis, syntactic analysis.

Several linguistic data, however, can not clearly be attributed to one of these categories, and it is language divesity with its subsets and detailed system of (lexical) headword markers that turns particular aspects of rule-based language generation into a gamble. Among the questions still to be answered, the most complex and therefore essential, seems to be the following:

To what degree are natural languages regular languages?

3 Fuzzy Real-World Items Demand Fuzzy Simulation

My suggestion is to discuss software retrieval systems where software components are represented by their natural language descriptions. The focus is to improve recall, precision and reasonable creativeness, that is to include the evidence of imperfection, exception, singularity, fault and error – probably the most specific and characteristic aspect of (human) life, in our context being technocratically reduced to a living neural system. Simulation of natural language in artificial intelligence as well as simulation of neural behaviour in robotics have still not yet provided best results, probably because the applied adaptive neural networks do not allow their systems – neural or not – to commit the same amount of faults, sometimes even crucial ones, as human beings have to during their life. As we know, the basic principle of any neural network is to learn from and develop within a data set given, to generate new data from an existing input. AI-experts have unfortunately forgotten to implement faults and mistakes, so that the neural network can improve on the original input by 'trial and error'. Success and progress, evolution even, could therefore memetically be interpreted as the cummulation of mistakes and respective reaction, a more sophisticated explanation of the frequently quoted 'Learning by doing'. That is exactly the point where traditional analysis fails to function as it does not provide smart solutions and real-world-based explanations for derivation, irregularity and error of any kind, yet inherent to any system. Consequently, the modelling and data processing of a phenomeneon such as natural language, where the status of perfection can always only be reached to some degree, may be foun in other methodologic options. As Bart Kosko reveals, it is the vagueness, grayness, uncertainty and mutivalued logic that

paves the way to fuzzy systems that raise the machine IQs of electric shavers and microwave ovens and robot arms on space shuttles. […] the fuzzy set is not a fad idea or computer gadget or exception to somebody's black-and-white rule. The fuzzy set is a hallmark of human and machine intelligence, the pure wedding of symbol and idea, the way we cope with a gray world. The fuzzy set is expressive. (Kosko 1994: 123, original marker)

In contrast to traditionally applied techniques, an adaption of fuzzy sets provides a new approach based on the systemic functional theory to represent the software components. Simulating or modelling natural language according to real-world and real-time expectations must take fuzzy components of human language into account, e. g. the theme-rheme aspect, language diversity, continuum aspects of linguistically detemined categories, textual meaning and other subsystems of the language system, all of which have consequently resisted precise analysis. Taking into account the uncertainty and vagueness related to natural language, the incompleteness of users' queries and the multiple-view classification of software components, a fuzzy representation with respect to some measures is derived by the thematic analysis of texts, with text being interpreted as a universe of discourse.

As to the methodological imperative, that the modelling of stated fuzzy real-world phenomena require fuzzy solutions, different types of combined devices such as Neuro-Fuzzy systems (Fullér 2000) must be discussed. This combination of fuzzy sets and neural networks (Zell 1996) enables adaptive systems to cope with multivalence, that is ambigue factors, uncertainty or undefined categories and, despite all analytic effort, also for linguistic subsets. If being is being but only to some some degree, modelling and simulation of real-world phenomena can only succeed, if they stop trying to be more exact than the real-life phenomenon itself. To avoid any misunderstanding: Classic approaches dealing with inexactness like probability math, still operating within binary paradigms, fail to function here and it could have taken a reasonabe amount of time until scientists and philosophers could were convinced that predicate logic or probability math have essentially missed phenomena such as subsethood or vagueness by mistaking them as some kind of randomness or probability. These misinterpretations have led to a long and intensive interlinguistic debate, whether vague, ambigue, imprecise entities of natural languages such as meaning, semantics or language diversity should be at all objective to scientific linguistic research (e. g. Bloomfield's behaviorism or certain aspects of gererative grammar). All linguists, from the ancient Greek philosophers or Confucius to the likes of Bloomfield, the early Wittegenstein (Tractatus logico philosophicus), de Saussure, Martinet or the founder of distributionalism, Harris, have faced the same serious methodological threat: If in any bivalent analytic therory there is only one element or subset that cannot be precisely examined and analytically determined, the whole theory collapses as it turns into a multivalued, fuzzy theory. Unfortunately, it was either the most essential aspect of natural languages, the meaning of an utterance, or the smallest analytically determined entity (e.g. the phone in phonetics, the seme in structural semantics, the smallest unit to form a sentence, etc.) that resisted final analytic definition. It was just a consequence, that, since the 1970's, vague, although not explicitly fuzzy theorems have conquered linguistic domains leading to a substantial paradigm shift, however, an all over fuzzy-based approach of natural language does still not exist. This is astonishing in so far as fuzzy entropy allows for an overall implementation of black-and-white schemes, analytically distinguished entities and sharp categories as extreme forms of fuzzy categories and patterns.

Before we discuss concrete fuzzy interpretations of language diversity, we will closer examine further developped approaches such as test-scoe semantics, which could later serve as an integrative fuzzy view of language diversity, too.

4 Test-Score Semantics – Fuzzy Approaches for Linguistic Categories

Test-score semantics is based on the premise that almost everything that relates to natural languages is a matter of degree. Seriously challenging the classic binary interpretation of natural language, most of all linguistic structuralism and its theorems, any semantic entity in a natural language, e. g. a predicate, predicate-modifier, proposition, quantifier, command, question, etc. may be represented as a system of elastic constraints on a collection of objects or derived objects in a universe of discourse, the context in other words. In this sense, test-score semantics may be viewed as a generalization of truth-conditional, possible-world and model-theoretic semantics as a real-world simulation, but its expressive power is substantially greater.

Test-score semantics represents a break with the traditional approaches to semantics in that it is based on the premise that almost everything that relates to natural languages is based on multivalued logic and therefore beyond the methodologic means of binary, analytic theorems, linguistic or other. The acceptance of this premise entails an abandonment of bivalent logical systems as a basis for the analysis of natural languages and suggests the substantial, holistic replacement by fuzzy sets as the basic conceptual framework for dealing with natural languages. As mentioned above, this methodologic approach does not necessarily mean the general exclusion or unvalidity of bivalent results, as bivalence is an extreme form within multivalence. Thus, a commitment to fuzzification does not preclude the use of bivalent logic when appropriate. In effect, such a commitment merely provides a language theorist with a much more flexible framework for dealing with natural languages and a means for representing meaning, knowledge and language diverstity as one of the particularly fuzzy ‘parole’-aspects of human language, as de Saussure might have interpreted it.

An essential proof for the effectiveness of a meaning-representation system is its ability to provide a basis for inference from premises expressed in a natural language. In this regard, test-score semantics provide its capability and applicabiltiy and serve as an indication of the general statement, that natural language is a fuzzy phenomeneon with limited subsets that could be exposed to analytic approaches. Under these ideas several fuzzy linguistic IRS models have been proposed using the tools of fuzzy linguistic approach to model the weights in the query and evaluation representation levels of (electronic) modelling/simulation of natural language. The fuzzy linguistic approach is an approximate technique, which represents qualitative aspects as linguistic values by means of linguistic variables, that is, variables whose values are not numbers but words or sentences in a natural or even artifcial language.

5 Man-Machine Communication – Does it Cope with Language Diversity?

The potential use of a natural language to facilitate human interaction with computers has been discussed for over three decades; the participants have disagreed about the feasibility and even the desirability of natural language programming, question-answering systems and, in case of fuzzified automation of language entities, the application of IF-THEN-rules. As I have already pointed out, allowing the use of unrestricted natural language is technically unfeasible and likely to remain so in the foreseeable future, therefore we have accepted the methodological necessity to deal only with restricted subsets. Consequently, subsets of natural languages must be used for communicating with computers. These subsets would be harder to learn and use than traditional formal computer languages because of interference with natural language usage habits. Providing a large enough subset of a natural language to be useful is an exceedingly difficult intellectual activity, requiring not only a far greater command of linguistic sets than is likely to be available for many years, but also requiring capabilities for representing an enormous quantity of information about the world and for efficiently drawing deductive and inductive conclusions from that input. Most simulation devices try to overcome inherent difficulties of natural language understanding for language processing by refering to the generative model of‘deep structure’ and ‘surface structure’. However, any processing system whose syntactic component is a phrase structure grammar of any kind can hardly cope with the underlying meaning relationships from the scrambled and incomplete forms that natural language input queries frequently take. Subsets and entities of language diversity feature prominently among input data interpreted by electronic processing systems as scrambled or incomplete. Phrase structure grammar-based systems must decode intended meaning from surface structures, yet it is well known that the semantic interpretation of surface structure is difficult. Wild ambiguity assigned to unambiguous sentences is a special case of the general lack of correspondence between surface structues and intended meaning – and any of the subsets concerning language diversity (sociolinguistics, dialectology, language registers, etc,) underline the necessity of a syntactic component for language processing that provides a more adquate structure than surface structure.

6 Fuzzy Control for Modelling Subsets of Language Diversity

Chomsky grammars, neither their linguistic approach nor their implementation as a means of language modelling in artificial intelligence provide satisfactory results. Potential ways of fuzzifiying language data with a possible representation of the most unique and unsystematic realisation of entities of language diversity must go along with a fundamental paradigm shift in theory and methodology of their linguistic interpretation. As far as natural sciences are concerned, this paradigm shift happened much earlier, as it was Heisenberg, who stunned the scientific world in the 1920's with the 'uncertainty' principle of quantum mechanics. He showed that one can look closer and know less. Together with Russell, the great mathematician who had shown that logic in the human mind is uncertain, Heisenberg had proven that even in physics the truth of a statement is a matter of degree. Now, in the times of a revival of quantum technology in programming and processing, once again scientific progress seriously threatens the fatal dominance of black-and-white categorization – another attempt to encourage people to question bivalent logic. As it makes the world face multivalued logic, there is some hope for fuzzy theorems to become the general application for programming and processing devices. Traditionally, paradigms for language diversity are paradigms applicable to the memetic inheritage of precise analysis and so, culturally secured by a long lasting monopoly. A look into print-based or even recently developed electronic versions of what is usually called a 'language atlas' in dialectology proves that this trap is still working effectively. Basically all of them put down the continuum of phonetic diverstiy or the continuum of the use of different lexical types in different regions to the bivalent methodologic means of simple maps with sharp borderlines and clearly seperated regions. Categories are not ambigue, even the aspect of overlapping domains is represented as an exception from otherwise clearly identified items. Traditional thinking leaves its traces not only within the linguistic understanding but, even more fatal, in the electronic programming features themselves. This is evident for all Windows-based applications strictly obeying the rules of Aristotle's bivalent categorization by way of digitalizing them.

As we aim to develop solutions beyond binary logic for electronic processing of subsets of language diverstiy, closer to the vague character of natural languages and considering the potentially indefinite, creative aspect of the human language, we have to start with a fundamental paradigm shift on each of the three above mentioned levels. Each of them needs adaption to the specific demands of an originally vague theory. As we saw, artificial intelligence has already provided us with the corresponding technology that should be capable of imitating and generating natural language, corresponding to their autoadaptive, creative character. Artificial neural networks, based on the fuzzy rules of multivalence are a true challenge for up-to-date electronic language processing, despite some criticism concerning their efficiency (Marcus 2001). As natural languages resemble multivalence-based subsets, the defining and describing forms and methods should be of the same type in order to obtain plausible values. Hans-Jürgen Zimmermann (1999), partner of Zadeh in various projects, gives a precise description of the miss-match problem between the object to be described and the method for description chosen. This methodological miss-match automatically occurs if uncertainty is to be modelled. Within natural language, elements of vagueness can be found e. g. among the potentially indefinite number of autosemantic words, the system of potential sociolingusitic markers, the phonetic differences in dialects or the aspects of categorization of collocations, etc. Traditional reasoning and methodologic attempts certainly represent the deterministic model (e. g. structuralism, binary logic, lexicographic definition, etc.) and this article would not be necessary if those deterministic explanations were not of a certain efficiency together with the enormous advantage of a well defined, static data set (e. g. corpus). However, deterministic, positivistic descriptions of natural language simplify and partially neglect the essential character (multivalence) of the object to be described.

Figure 1 presents the three levels of consequently fuzzified language modelling, that is after a revision of the programming/processing device, the linguistic interpretation of natural language and its hypermedia presentation according to fuzzy rules and sets.

Applications in industry/pilot versions	**Level 1 Programme structure**	**Level 2 Object/content to be described (here: language diversity)**	**Level 3 Presentation/ Design**
■ Fuzzy-Control ■ (PID-controller, IF-THEN-automatisation) ■ Neuro-Fuzzy systems ■ ANFIS ■ IRIS ■ NEFCON ■ NEFCLASS ■ NEFPROX	■ artificial neural networks (fits) ■ autoadaptive systems, autocreative and learning from their own past ■ variable data-structure, changing with and adapting to the habits and demands of the user	■ continuum-linguistics drawing no sharp lines between linguistic categories (synoyms and antonyms are elements within one and the same continuum) ■ non deterministic theories ■ constructivist models preferred to the idea of representation	■ dynamic ■ imitating the neural network ■ varoius hypermedia options ■ continuum of colours instead of contrasts ■ no boxes/windows ■ as there is no fixed data set, the language units do not have fixed/secured positions

Figure 1
Fuzzified levels for the processing of language data as a real-world phenomenon

References

[1] Kenneth Aizawa: Representations without Rules, Connectionism and the Syntactic Argument, in Synthese 1994/101, pp. 465-492

[2] Robert Aunger (ed.): Darwinizing Culture: the Status of Memetics as a Science, Oxford: Oxford University Press, 2000

[3] Blackmoore, Susan (2000) *Die Macht der Meme oder die Evolution von Kultur und Geist*, Heidelberg: Spektrum Akademischer Verlag

[4] Jay D. Bolter: Writing space. Computers, hypertext and the remediation of print. Mahwah/NJ: Lawrence Erlbaum Associates, 2001

[5] Robert Fullér: Introduction to Neuro-Fuzzy Systems, Heidlberg: Physica-Verlag (Advances in Soft Computing), 2000

[6] Siegfried Gottwald: Mehrwertige Logik und unscharfe Mengen (Multivalued logic und vague catgories), in Fuzzy Theorie und Stochastik. Modelle und Anwendungen in der Diskussion, ed. Rudolf Seising, Braunschweig & Wiesbaden: Verlag Viehweg, 185-202 (Computational Intelligence) Kommers, Piet & Ferreira, Alcindo F. & Kwak, Alex W. (eds.) (1998) Document management for hypermedia design, Berlin & Heidelberg: Springer, 1999

[7] Bart Kosko: Fuzziness vs. Probability, in International Journal of General Systems 1990/17 (2-3), pp. 211-240

[8] Bart Kosko: Fuzzy Thinking. The New Science of Fuzzy Logic, London: Harper Collins Publishers. 1994

[9] Aarre Laakso & Garrison Cottrell: Content and Cluster Analysis: Assessing Representational Similarity in Neural Systems, in Philosophical Psychology 2000/13, pp. 47-76

[10] Ulrich H. Langanke: Fuzzy Logic als Grundlage für das hypermediale Online-Wörterbuch – Unschärfe als Programmierungs- und Gestaltungsprinzip (Fuzzy logic in hypermedia online-dictionaries – vagueness in programming and processing), in Praktische Aspekte der Lexikographie. Beiträge des Lexikographischen Workshops am 16.-17. Oktober 2003 an der Eötvös-Loránd-Universität Budapest, eds. Koloman Brenner & Roberta Rada, Budapest: ELTE Germanistisches Institut, 146-157 (Budapester Beiträge zur Germanistik, Vol. 48), 2005

[11] Ulrich H. Langanke: Fuzzy strategies in Hypermdia-Online-Dictionaries – solutions beyond binary logic, in A világ nyelvei és a nyelvek világa. Soknyelvűség a gazdaságban, a tudományban és az oktatásban, XV. Magyar Alkalmazott Nyelvészeti Kongresszus, Miskolc, 2005. április 7-9, Vol. 2, eds. Kinga Klaudy & Csilla Dobos, Miskolc: Passzer 2000, pp. 280-285, 2006a

[12] Ulrich H. Langanke: Neuro-Fuzzy-Systeme für die Hypermedialisierung linguistischen Datenmaterials. Am Beispiel von Dia-Markierungen (Neuo-Fuzzy systems for linguisitc data sets in hypermedia applications. Headword markers as an example), in Diahronija in sinhronija v dialektoloških raziskavah, eds. Mihaela Koletnik &Vera Smole, Maribor: Dravska tiskarna, pp. 267-276, 2006b

[13] Gary Marcus: The Algebraic Mind, Cambridge/Mass.: MIT Press, 2001

[14] Detlef Nauck & Frank Klawonn & Rudolf Kruse (eds.): Neuronale Netze und Fuzzy-Systeme. Grundlagen des Konnektionismus, Neuronaler Fuzzy-Systeme und der Koppelung mit wissensbasierten Methoden, Braunschweig & Wiebaden: Verlag Viehweg (Computational Intelligence), ^{2}1996

[15] Lotfi Zadeh: Fuzzy Sets, in Information and Control 1965/8, pp. 338-353

[16] Lotfi Zadeh: Probability measures of fuzzy events, in Journal of Mathematical Analysis and Applications 1968/23, pp. 421-427, 1968

[17] Lotfi Zadeh: PRUF – a meaning representation language for natural languages, in International Journal of Man-Machine Studies 1978/10, pp. 395-460, 1978

[18] Lotfi Zadeh: Test-score semantics for natural languages and meaning-representation via PRUF, in Technical Note 247, AI Center, Menlo Park/Ca.: SRI International, 1981

[19] Lotfi Zadeh: Fuzzy Sets and Applications: Selected Papers, eds. Ronald Yager, Sergei Ovchinnikov, Richard Tong and Hung T. Nguyen. New York: John Wiley & Sons, 1987

[20] Zell, Andreas: Simulation Neuronaler Netze, Bonn & Paris & Reading/Mass. [a. o.]: Addison-Wesley, 1996 Zimmermann, Hans-Jürgen (1999): Zur Modellierung von Unsicherheit realer Probleme (Modelling of uncertainty of real-world problems), in Fuzzy Theorie und Stochastik. Modelle und Anwendungen in der Diskussion, ed. Rudolf Seising, Braunschweig & Wiesbaden: Verlag Viehweg, 287-301 (Computational Intelligence)