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EDITOR'S NOTE

This newsletter is produced and distributed by the CENTER FOR RESEARCH IN LANGUAGE, a research center at the University of California, San Diego that unites the efforts of fields such as Cognitive Science, Linguistics, Psychology, Computer Science, Sociology, and Philosophy, all who share an interest in language. We feature papers related to language and cognition (1-10 pages, sent via email) and welcome response from friends and colleagues at UCSD as well as other institutions. Please forward correspondence to:

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SUBSCRIPTION INFORMATION

If you are currently receiving a hardcopy of the newsletter only and have an email address to which the newsletter can be sent, please forward that information to CRL.

Can we send you the email version only to save printing and mailing costs? If you require a hardcopy in addition, please request it and we will be happy to send you one.

If you require the unformatted nroff version of the newsletter, please request it from CRL after you have received the current regular formatted version.

If you know of others who would be interested in receiving the newsletter, please forward the email or postal mailing address to CRL. Thank you.

BACK ISSUES

Back issues of this newsletter are available from CRL in hard copy as well as soft copy form. Papers featured in previous issues include the following:

The Cognitive Perspective
Ronald W. Langacker
Department of Linguistics, UCSD
vol. 1, no. 3, February 1987

Toward Connectionist Semantics
Garrison Cottrell
Institute for Cognitive Science, UCSD
vol. 1, no. 4, May 1987

Dimensions of Ambiguity
Peter Norvig
Computer Science, UC Berkeley
vol. 1, no. 6, July 1987

Where is Chomsky's Bottleneck?
S.-Y. Kuroda
Department of Linguistics, UCSD
vol. 1, no. 7, September 1987

Transitivity and the Lexicon
Sally Rice
Department of Linguistics, UCSD
vol. 2, no. 2, December 1987

Formal Semantics, Pragmatics,
and Situated Meaning
Aaron Cicourel
Department of Sociology, UCSD
vol. 2, no. 3, January 1988

Rules and Regularities in the
Acquisition of the English Past Tense
Virginia Marchman
Department of Psychology, UC Berkeley

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A Geometric Conception of Grammar
S.-Y. Kuroda
Department of Linguistics, UCSD
vol. 2, no. 5, June 1988

Harris and the Reality of Language
S.-Y. Kuroda
Department of Linguistics, UCSD
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A Connectionist Perspective on Prosodic Structure
Mary Hare, Dept. of Linguistics, UCSD
David Corina, Dept. of Psychology, UCSD
G.W. Cottrell, Dept. of Computer Science, UCSD
vol. 3, no. 2, November, 1988

Competent Scientist Meets the Empiricist Mind
Valerie Walker
Department of Philosophy, UCSD
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Foreign Policy By Metaphor
Paul Chilton, University of Warwick, U.K.
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Guarani Possessive Constructions
Maura Velazquez
Department of Linguistics, UCSD
vol. 3, no. 6, July, 1989

Anticipatory Coarticulation and Aphasia: Implications
for Connectionist Models of Speech Production
William F. Katz
Department of Psychiatry, UCSD
vol. 4, no. 1, December, 1989

SPECIAL ANNOUNCEMENT

I am pleased to announce that Professor Elizabeth Bates (Departments of Cognitive Science and Psychology) has been appointed Associate Director of CRL, effective February 1, 1990.

--Jeffrey Elman, Director

P L E A S E   P O S T

RESEARCH AND TRAINING PROGRAM IN NEURAL MODELING FOR DEVELOPMENTAL PSYCHOLOGISTS

Center for Research in Language
University of California, San Diego
La Jolla, California 92093

The Center for Research in Language at UCSD is beginning the second year of its Neural Network Training Program for developmental psychologists. The program is funded by the John D. and Catherine T. MacArthur Foundation and will provide 5 - 10 developmental psychologists at any level (dissertation students through senior investigators) with short-term training in neural computation. The program has two goals:

(1) To encourage developmental psychologists in target interest areas (speech, language, early visual-motor and cognitive development, future oriented processes) to begin making use of connectionist modelling as a tool for evaluating theories of learning and change;

(2) To encourage greater use of realistic developmental data in the connectionist enterprise.

Our experience at UCSD suggests that a well-prepared and computer literate developmental psychologist can learn to make productive use of neural modelling techniques in a relatively short period of time, i.e. 2 weeks to 3 months, depending on level of interest and prior experience. Applicants may request training periods in this range at any point from 7/90 through 8/91. Depending on the trainee's needs and resources, we will provide (1) lodging at UCSD, (2) travel (in some cases), (3) access to SUN and VAX workstations with all necessary software, and (4) hourly services of an individual programmer/tutor who will supervise the trainee's progress through self-paced learning materials while assisting in the implementation of the trainee's proposed developmental project. Trainees are also welcome to attend seminars and workshops, and to consult with the relatively large number of faculty involved in connectionist modelling at UCSD.

Applicants are asked to submit 5 - 10 page proposals outlining a specific modelling project in a well-defined domain of developmental psychology. Criteria for evaluating proposals will include (1) the scientific merit and feasibility of the project itself (2) the applicant's computer sophistication and probability of success with short term training, (3) the probability that the applicant can and will continue working at the interface between neural modelling and developmental psychology (including access to adequate computer facilities at the applicant's home site). Applicants should indicate the preferred duration and starting date for the training program.

Applications should be submitted to Jeff Elman, Director, Center for Research on Language, University of California, San Diego, La Jolla, Ca. 92093. For further information, contact Jeff Elman (619-534-1147) or Elizabeth Bates (619-534-3007). Email inquiries may be sent to elman@ amos.ucsd.edu or bates@ amos.ucsd.edu.

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The Role of Similarity in Hungarian Vowel Harmony:
A connectionist account

Technical Report CRL-9004

Mary Hare
UCSD Department of Linguistics
and
Center for Research in Language
University of California, San Diego

Over the last 10 years, the assimilation process referred to as vowel harmony has served as a test case for a number of proposals in phonological theory. Current autosegmental approaches successfully capture the intuition that vowel harmony is a dynamic process involving the interaction of a sequence of vowels; still, no theoretical analysis has offered a non-stipulative account of the inconsistent behavior of the so-called "transparent", or disharmonic, segments.

The current paper proposes a connectionist processing account of the vowel harmony phenomenon, using data from Hungarian. The strength of this account is that it demonstrates that the same general principle of

assimilation which underlies the behavior of the "harmonic" forms accounts as well for the apparently exceptional "transparent" cases, without stipulation.

The account proceeds in three steps. After presenting the data and current theoretical analyses, the paper describes the model of sequential processing introduced by Jordan (1986), and motivates this as a model of assimilation processes in phonology. The paper then presents the results of a series of parametric studies that were run with this model, using arbitrary bit patterns as stimuli. These results establish certain conditions on assimilation in a network of this type. Finally, these findings are related to the Hungarian data, where the same conditions are shown to predict the correct pattern of behavior for both the regular harmonic and irregular transparent vowels.

Copies of this report may be obtained by sending an email request for TR CRL-9004 to yvonne@amos.ucsd.edu, or surface mail to the Center for Research in Language, C-008; University of California, San Diego; La Jolla CA 92093.

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CONNECTIONIST MODELS SUMMER SCHOOL / SUMMER 1990

UCSD
La Jolla, California

The next Connectionist Models Summer School will be held at the University of California, San Diego from June 19 to 29, 1990. This will be the third session in the series which was held at Carnegie Mellon in the summers of 1986 and 1988. Previous summer schools have been extremely successful, and we look forward to the 1990 session with anticipation of another exciting summer school.

The summer school will offer courses in a variety of areas of connectionist modelling, with emphasis on computational neuroscience, cognitive models, and hardware implementation. A variety of leaders in the field will serve as Visiting Faculty (the list of invited faculty appears below). In addition to daily lectures, there will be a series of shorter tutorials and public colloquia. Proceedings of the summer school will be published the following fall by Morgan-Kaufmann (previous proceedings appeared as 'Proceedings of the 1988 Connectionist Models Summer School', Ed., David

Touretzky, Morgan-Kaufmann).

As in the past, participation will be limited to graduate students enrolled in PhD. programs (full- or part-time). Admission will be on a competitive basis. Tuition is subsidized for all students and scholarships are available to cover housing costs ($250).

Applications should include the following:

(1) A statement of purpose, explaining major areas of interest and prior background in connectionist modeling (if any).

(2) A description of a problem area you are interested in modeling.

(3) A list of relevant coursework, with instructors' names and grades.

(4) Names of the three individuals whom you will be asking for letters of recommendation (see below).

(5) If you are requesting support for housing, please include a statement explaining the basis for need.

Please also arrange to have letters of recommendation sent directly from three individuals who know your current work.

Applications should be sent to

Marilee Bateman
Institute for Neural Computation, B-047
University of California, San Diego
La Jolla, CA 92093
(619) 534-7880

All application material must be received by March 15, 1990. Decisions about acceptance and scholarship awards will be announced April 1. If you have further questions, contact Marilee Bateman (address above), or one of the members of the Organizing Committee.

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Andy Barto (UMass/Amherst)   Jay McClelland (CMU)
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Michael Jordan (MIT)   Halbert White (UCSD)
Teuvo Kohonen (Helsinki)   Ron Williams (Northeastern)
George Lakoff (UCB)   David Zipser (UCSD)

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Toward a Connectionist Representation of Grammatical Knowledge

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1. Introduction

The Parallel Distributed Processing (PDP), or "connectionist" research program, seeks correspondences between the representational and processing capacities of networks of simple processing elements and general cognitive phenomena (McClelland & Rumelhart, 1986; Smolensky, 1988. To the extent that diverse aspects of cognition are shown to be amenable to modeling in network form or to be describable in connectionist terms, this research program is supported. But finding such matches can do more than support PDP tenets. The existence of connectionist mechanisms can bolster the appeal of theoretical approaches that might otherwise appear implausible, difficult to understand or simply out of step with dominant conceptions of mental functioning.

Linguists working in the theoretical framework called cognitive linguistics argue that revealing description of linguistic phenomena is impossible without reference to the cognitive capabilities of language users (Lakoff, 1987; Langacker, 1987, in press, and others). Cognitive linguists share with functionalist linguists the working hypothesis that the function of language (communication) constrains the range of grammatical forms within and between natural languages (Bates & MacWhinney, 1982, 1989; Givon, 1979, 1989). Workers who take this cognitive/functionalist approach have described grammar as a system for coding the relationship between utterances and their meanings. The coding is viewed as relatively direct: a grammar is a list or inventory of mappings between utterances and their semantic and pragmatic interpretation. Properties of the coding system are thought to include: (a) grammatical rules are exemplified by utterance-meaning pairs in the inventory, and may not be explicitly represented; (b) regularities among input-output pairs are abstracted and become the basis for the production and comprehension of novel expressions; (c) much of grammatical competence consists of the manipulation of conventional expressions; (d) prototypes emerge when similar patterns reinforce each other; (e) irregular patterns are maintained if favored by frequency; (f) a rich set of cognitive capabilities underlies and constrains the linguistic coding of events.

The conceptual compatibilities between connectionism and the cognitive/functionalist approach to language have been noted by a number of researchers. Langacker (CRL Newsletter, volume 1, issue 3) has described the desirability of a system which can accommodate both rule-governed and idiosyncratic patterns. Cottrell (CRL Newsletter, volume 1, issue 4) points out that distributed representations might be useful for capturing the subtle differences in meaning that occur when words are used in different contexts. In previous work (Harris, 1989, submitted) I elaborated this point and showed how aspects of Brugman and Lakoff's (1988) analysis of the polysemes of the preposition over are extracted and exploited by a network trained on pairs of sentences and their meanings. The convergence between connectionist capabilities and theoretical constructs is further illustrated by the work of Bates and MacWhinney (1989) and colleagues (MacWhinney, Leinbach, Taraban & McDonald). The extraction of regularities in a back propagation network resembles their performance model of how speakers detect valid cues to meaning.

My goal in the current paper is to describe how the characterization in (a)-(f) above poses computational problems which might be met by connectionist networks. I first present some of the motivation for adopting a cognitive/functionalist perspective. I will then focus on one theoretical formulation of this approach, Langacker's (1987, in press) cognitive grammar, selecting as example phenomena Rice's (1987) cognitive analysis of transitivity and Langacker's (in press) conceptual characterization of the grammatical subject relation. Space limitations prohibit the presentation of the detailed arguments that would establish the validity of these controversial positions. But even if one accepts the intuitive appeal of Rice's and Langacker's linguistic analyses, one could question whether these ideas are susceptible to precise and rigorous expression. Conceiving of a grammar as a mapping carried out by a connectionist network would provide a method for defining such constructs as prototype, schema and linguistic regularity. Researchers are beginning to understand how the frequency and reliability of mappings, combined with resource limitations, determine the course of learning and the development of internal representations. Thus, even in the absence of an actual network model, our understanding of these and other connnectionist principles may be able to constrain our characterization of language representation and use.

2. Grammar as a Set of Form-Meaning Pairs

Linguists of all theoretical persuasions concur in viewing grammar as a system for coding communicative intent. The goal of linguistic theory is to characterize the properties of this coding system. Generative grammarians have long believed a key property to be that the coding system can not be defined or described with reference to conceptual entities: the properties of grammars must be described in purely linguistic terms. Description is undertaken with a purpose, and a historical goal of the generative paradigm has been to devise a method for constructing perfectly explicit grammars. An explicit grammar is one which can be described without relying on the intelligence of the understanding reader (Chomsky, 1965). Beginning with Chomsky (1957) this has been conceived to be a machine or formal device which could generate all and only the grammatical sentences of a language.

A desire to be rigorous and explicit can only be lauded. The adoption of Chomsky's explicitness criterion, however, precludes theorists from seeking to understand the properties of the coding system as a function of or even influenced by the communicative goals of language users, human information processing mechanisms, or any other uncompletely formalized psychological entity. This is an unfortunate exclusion because these are the information sources that are intuitively plausible as explanatory parameters. That is, if one wants to explain why linguistic coding systems have the forms they have, it seems natural to investigate the purpose of the coding system. For example, if we wanted to explain the structure of Morse code, we would turn to the reasons the code is used, the transmission devices available at the time of the code's development, and the information processing abilities of the code's users. The explanatory goals of functionalist and cognitive grammarians are similar to these in that they seek to understand how surface devices such as variations in word order, constituency relations, and case and agreement systems are determined by communicative goals, the pragmatics of the speech situation, and the human cognitive apparatus.

It is easy enough to understand that functionalist grammarians view the function of a grammar to be the encoding and decoding of messages. But how do they define a grammar? I will abstract over some differences in terminology and emphasis among different theorists (eg., Bates and MacWhinney, 1982, in press; Langacker, 1987; Lakoff, 1987) and define it as a conventionalized set of form-meaning pairs and schematizations over form-meaning pairs. A form is an actual or possible utterance. Meaning is broadly conceived to encompass all evoked conceptualization, including communicative function and extralinguistic aspects of the speech act. A schematization, or, schema, is an abstract or less specific variant of a form or a meaning. It is typically used to describe the invariances in a large set of overtly occurring forms or meanings. Schemas can be relatively specific, as would be the case for idiosyncratic expressions whose conditions of form and usage speakers must memorize, or they can be highly abstract, as in the schematic structure which specifies canonical word order. These abstract pairs are called symbolic units by Langacker (1987) and constructional schemas or grammatical constructions by Lakoff (1987) and Fillmore (1988). Under this interpretation of a grammar, all grammatical forms have a conceptual basis, although often a highly abstract one. There is thus no clear separation between grammar, semantics, and pragmatics, since semantic and pragmatic structures are included in the grammatical constructions.

One early motivation for viewing a grammar as a set of constructional schemas was to extend the coverage of grammatical theory to so-called "peripheral constructions," such as idioms and conventional expressions. Fillmore (1986, 1988) has described how a great deal of a language user's competence consists in the manipulation of idioms and stock phrases, such as the following: learn by heart, know by heart, cook his/her NP's goose, I wouldn't VP if you gave me NP, the more S the more S, take X to task for Z, take NP for granted. Because many of these patterns are productive, Fillmore points out that the machinery required to handle them would be powerful enough to accommodate more regular patterns. It is thus reasonable to seek a conception of a grammar which treats these partially regular patterns in the same way as the more regular, canonical grammatical constructions of a language.

Cognitive linguists do not reject the autonomy of syntax hypothesis soley because peripheral expressions have a pragmatics and syntax that don't follow in a regular way from their syntactic form. Such classic grammatical problems as determining the constraints on the acceptability of passive sentences, noun-phrase extraction, and pronominal reference have proved difficult to characterize on such formal bases as phrase structure configuration or verb argument structure. Considerable success has been achieved by describing these constructions in conceptual terms: Kuno (1987) and Kluender (1989) describe semantics factors constraining noun-phrase extraction, Van Hoek (1990), Kuno (1987) and Bosch (1983) present cognitive accounts of anaphora, and Hopper & Thompson (1980), Rice (1987), Langacker (1982) and DeLancey (1987) argue that conceptual notions underlie transitivity and passivization.

To illustrate the application of the cognitive grammar approach to standard linguistic problems, I describe in the following sections Rice's (1987, CRL Newsletter, volume 2, issue 2) cognitive account of transitivity and passivization, and Langacker's (in press) conceptual formulation of grammatical subject.

2.1. A prototype model of transitivity

It has long been recognized that only some transitive clauses can passivize. Researchers have traditionally explained this by dividing verbs into categories and specifying the conditions under which verbs in each category can be used in a passive construction (Bresnan, 1982; Pinker, Lebeaux & Frost, 1987). In contrast, Rice (1987) has demonstrated that whether a transitive sentence has a passive form is due to elements in the entire clause, including the speaker's subjective conceptualization of the clausal activity.

Rice argues that when speakers use a transitive clause to describe a given event, they implicitly take a particular perspective on the event. A transitive clause is prototypically used to depict an energetic interaction between two scene participants. The action proceeds unidirectionally from one participant to the other, is volitional, and induces a change of state in the recipient of the action. The extent to which the events described by a clause conform to this prototype affects its transitivity and thus the extent to which it can undergo passivization. For example, John left the auditorium does not passivize well, but John left the auditorium unguarded does produce an acceptable passive. In the former utterance, it is difficult to view the auditorium as a participant in an energetic interaction. But in the latter, we infer that John's leaving the auditorium has some affect on or direct relevance for the auditorium (it may be vulnerable to unauthorized entry). Once the auditorium is conceptualized as being affected by John's action, it becomes a participant rather than merely an event setting.

2.2. A cognitive definition of the subject relation

Linguists have long noted that grammatical subject cannot be equated with a pragmatic notion such as topic or a semantic notion such as agent. In passives -- the canonical non-agentive subject constructions -- the subject may be a newly introduced entity and thus not even the current topic. Often the sentence subject is an event, setting or itself a sentence. Givon (1979) has noted that cross-linguistically, subjects are most often agents and topics and that the pragmatic force of a passive is most frequently to focus attention on the recipient of action. This has led some theorists (Bates & MacWhinney, 1982; Van Oosten, 1987) to propose that subject is a prototype category. This proposal is certainly useful for understanding how children might acquire the adult abstract category of subject: they learn correlations between the conceptual categories topic and agent and the set of surface devices that code these functions (Bates, 1976; Bates and MacWhinney, 1979, 1982). But is it possible to come up with a characterization of subject which holds for non-prototypical as well as prototypical instances?

Langacker (in press) points out that "the subject's tendency to assume a pivotal role in grammatical structure is most reasonably regarded as symptomatic of some special cognitive salience that makes it particularly accessible." He suggests that when speakers confer subjecthood on a particular entity -- on the agent of an action, or, in marked clause structure, on a setting or event -- they are making it the primary clausal figure. The purpose of having a conventionalized device like subject is so that speakers have the power to elevate a discourse entity to the special status of figure, while relegating other entities to the status of ground.

How does this characterization of the subject relation fit into the general conception of a grammar as a set of schematic form-meaning pairs? "Subject" is defined as a relationship between language-dependent surface devices (for English these include status as a nominal, pre-verbal position, and agreement with the clausal verb) and the possibly universal function of elevation to the status of primary clausal figure. How is this schematic pair represented? Like all other abstract constructional schemas, it is viewed as immanent in the set of all form-meaning pairs of a language.

3. PDP Principles Constrain the Form-Meaning Mapping

How can PDP mechanisms be useful for researchers who accept the plausibility of the cognitive/functionalist approach to language? Langacker (1987) has described a grammar as a list or inventory of grammatical constructions. Linguistic analysis has compelled him and colleagues to view this list as having certain properties: (a) The list contains both exceptions to and instantiations of the dominant linguistic regularities. (b) Rules are not explicitly represented but are immanent in the inventory of form-meaning pairs. (c) The pairings of forms and meanings are conventional and language-specific and so are most reasonably viewed as learned. (d) A rich set of cognitive capabilities underlies and constrains the linguistic coding of events.

Establishing the linguistic merit of this characterization would require a more thorough presentation of the arguments than was attempted in the current brief report. Setting aside the issue of linguistic merit, positing that a grammar is a type of list poses computational problems. What combination of data and process would yield a mechanism which could produce the desired properties? This question becomes particularly acute for theorists who view the nature of a grammar to be intimately tied to its use in coding and decoding human communication.

As data structures, lists have little appeal. But once a list is conceived as being stored in a distributed format, the computational properties discovered by connectionist researchers accrue to it: prototypes emerge when similar patterns reinforce each other, irregular patterns are maintained if favored by frequency, and novel patterns can be generated or interpreted on analogy to familiar ones.

A network formalism appears a natural one for cognitive grammar because of the conceptual similarity between the types of mappings learnable by pattern associators and the notion that a grammar is a mapping between form and meaning. Advantages of conceiving of a grammar as a PDP network include the following:

> The network representation turns the static list into a mechanism in which many of the properties posited by cognitive linguists emerge naturally. In current descriptions by cognitive linguists, there is no mechanism for describing the conditions under which some classes of form-meaning pairs attain the status of an abstract schematization to which novel utterances can be assimilated. It is part of the common-sense appeal of the theory that (a) regularities among input-output pairs are abstracted and become the basis for the production and comprehension of novel expressions, and that (b) linguistic patterns which are irregular may still become part of a speaker's linguistic knowledge if they are highly frequent in a speech community. Instantiation in a PDP network allows formalization of these ideas.

> Although cognitive linguists such as Langacker (1987) and Lakoff (1987) do not address the problem of language learning, back propagation networks appear to be computationally isomorphic to a learning model proposed by Bates and MacWhinney (1982, 1987, 1989). Bates and MacWhinney have shown that the frequency and reliability of form-function mappings in the child's environment are the single most important predictor of early grammatical knowledge. The PDP formalism is thus appealing in that it provides a computational hypothesis about how grammatical form-function mappings are acquired by children.

If the proposal to view a grammar as a distributed representation of form-meaning pairs is to become a research program, at least three issues will need to be addressed: what types of connectionist models are appropriate, how is the conceptual interpretation of a linguistic utterance to be represented, and how should one view the vast bulk of linguistic phenomena whose amenability to connectionist modeling appears at the current time is difficult to imagine.

What types of connectionist models? Typically when a researcher selects a particular formalism or computational model, an attribute of the formalism is that precise conditions exist for determining what is and is not an instantiation of it. But the class of connectionist models and their computational properties is still being defined and explored. In the current paper I have avoided reference to particular models and have relied on the reader to understand that we seek mechanisms for accomplishing computational goals, such as extracting the regularities in a set of structured input-output pairs and parallel consideration of multiple information sources. In the ideal modeling world, architectures would evolve as the needs of the modeler are articulated. For example, I mentioned above that cognitive linguists view utterance production to be driven by the regularities speakers extract from encountering many input-output pairs. Clearly our grammar needs to be a representation of regularities which can be used for both production and comprehension. How is this to be achieved? A simple initial method would be to use two networks. For a given corpus of sentences, a modeler could construct semantic feature vectors representing the meaning. One network would be trained to map from form to meaning, and the other to map from meaning to form. To capture our intuitions that knowledge in one mapping influences the other, one could link (i.e., constrain to be similar) a portion of the weights in the two networks. A more sophisticated solution, however, might be a network in which both comprehension and production could coexist, influence each other, yet retain some modality-specific properties.

Representing mental conceptualizations. One of the legacies of the transformational-generative enterprise is that a great deal is known about grammatical structure and the behavior of different types of linguistic entities. There is as yet little concensus, however, on the mental conceptualizations which accompany use of these grammatical patterns. How is the meaning half of a form-meaning pair to be represented? I see no general scheme for this at the current time. Instead, researchers must select a coherent phenomena for modeling, and then define and defend a semantic representation for their corpus of utterances (cf. Harris, 1989, submitted; MacWhinney, Leinbach, Taraban & McDonald, 1989).

Phenomena not amenable to connectionist modeling. Langacker (1987) and Lakoff (1987) have emphasized that a crucial ability of language users is to construe the same scene from different perspectives, and to construct an infinitude of images for the same word or sentence. At the very least this implicates an attentional mechanism, as well as a host of cognitive processing abilities whose network instantiation is problematic. Many other aspects of cognitive linguistic theory similarly do not readily inspire a method of connectionist implementation. It appears impossible to determine now which phenomena will ultimately prove most recalcitrant to modeling, given our preliminary understanding of them and the youth of the connectionist modeling endeavour.

4. About Formal Models

The interaction between data, formal model, and explanation which come to constitute a theory may be both subtle and complex (Givon, 1979). No formal model ever perfectly meets the needs of data and explanation. Often a formalism becomes appealing to a scientific community because it allows rigorous expression of an idea which provides an answer to a currently pressing question. One could speculate that a large amount of the appeal of Syntactic Structures was that Chomsky formalized a notational system -- recursive rewrite rules -- which allowed an infinite set of sequences to be expressed by a finite mechanism. The existence of these rules provided a mechanism for addressing a pressing question of the time: how can a finite storage capacity (the brain) be the source of the ability to utter and comprehend an infinite number of sentences? By declaring a grammar to be a set of rules which were physically housed in the brain, Chomsky not only addressed the issue of linguistic productivity, but exhorted linguistics as a science to aspire to understand the more fundamental question of the nature of human knowledge.

If PDP networks become a method for formalizing notions from cognitive linguistics (and I have pointed out reasons why they are an appropriate computational vehicle), they will share a certain similarity with their historical predecessor, recursive rewrite rules. That similarity is that both notational systems vastly underconstrain the types of linguistic theory that may be constructed around them. PDP mechanisms are not a theory of language. But a theory of language built around connectionist principles is not being proposed. Many of the theoretical concepts laid out by cognitive linguists are sufficiently well-specified that instantiation in a PDP network would not signal the start of construction of a theory of language but would represent a middle stage of theory development: an opportunity to fine-tune some aspects and enlarge others, such as making contact with work in language acquisition and adult processing.

Does this imply that the role of connectionism should be to implement cognitive linguistic theory? No. It is questionable whether implementing a theory is ever a useful goal of computational modeling. Instead, one should model significant data with the aim of theory modification, disconfirmation, or extension. If we are compelled by the position that the structure of language is constrained by general information processing abilities, and that cognition is an emergent property of a connectionist microstructure, then the possibility of fruitful co-evolution of theories beckons: can we construct a theory of language which benefits from our understanding of connectionist concepts, and can we advance our conception of the microstructure as we better understand the nature of the linguistic structures and processes it must support?

[The author thanks Rik Belew for comments and welcomes feedback from readers.]

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