

COGNITIVE SCIENCES

*Basic Problems, New Perspectives,
and Implications for Artificial Intelligence*

MARIA NOWAKOWSKA

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MARIA NOWAKOWSKA

**Machine Intelligence Institute
Iona College
New Rochelle, New York**

1986



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**To the memory of my parents,
Jan and Anna Kowal**

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PREFACE

This book presents certain new models and theories that are designed to describe and analyze some selected topics in the cognitive sciences. These topics range from the relatively unexplored, such as problems of observability and its restrictions or distortions of the subjective perception of time, to those that are traditionally analyzed by cognitive scientists, such as visual perception, memory, and communication. In each case, the main efforts are directed at a new conceptual representation of the phenomenon analyzed, with appropriate mechanisms postulated and explanatory hypotheses formulated.

The book treats cognitive processes through a set of interrelated theories, from different perspectives and on different levels of generality. The main purpose is to deepen and extend the theoretical apparatus of cognitive processes so that they can become an “interdiscipline” useful for a wider class of sciences. Thus, the book abandons the information-processing paradigm and searches instead for new concepts and solutions in psychological intuitions and mechanisms. It stresses the problems of cognitive limitations and distortions on the one hand and the generative, controlled, and dynamic character of cognition on the other. The best example here is the interactional model of perception, in which one distinguishes four basic mechanisms assumed to be under partial control of the subject.

As already stressed, the book is based on a multimodel conception of analysis of cognition. The possibilities of a unification through more general models, such as formal theory of actions and formal semiotics (theory of object and sign) have been presented in earlier books of the author: “Quantitative Psychology: Some Chosen Problems and New Ideas” (Nowakowska, 1983) and “Theories of Research” (Nowakowska, 1984). These books form an important context and are complementary to the present book. It is also

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worthwhile to mention that both theories may be of direct interest for planning in robotics and knowledge representation of situation structure for Artificial Intelligence and Expert Systems (representation of knowledge about situation structure).

The book ends with some stochastic models of expertise formation, opinion change, and learning. These models allow a deeper connection between problems of the cognitive sciences and expert systems and AI.

The book is entirely original and is not intended to be a review of the literature on the subject. Therefore only those works that were actually used are referenced.

For other approaches, especially those related to the information processing paradigm in the cognitive sciences, see, for instance, Anderson (1980,1983), Grossberg (1982), Hayes (1978), Kosslyn (1980), Lindsay and Norman (1977), Minsky (1975), Neisser (1967), Newell and Simon (1972), Norman and Rumelhart (1975), Posner (1973), Rumelhart (1975), Shank and Abelson (1977), Shepard and Cooper (1982), Sowa (1984), or Townsend and Ashby (1983).

The book is intended for all those who deal with cognitive processes in their research and teaching; hence it should be of interest not only to social scientists but also to information scientists, artificial intelligence specialists, logicians, philosophers, psycholinguists, neurobiologists, and system specialists and engineers interested in cognitive problems.

The book assumes some mathematical background; in particular, a basic knowledge of the theory of relations, fuzzy set theory, and probability theory. To facilitate reading, the Appendix contains basic information about these theories and references to the literature; in addition, the theorems are explained on an intuitive level whenever possible and their proofs are given in appendixes to the chapters.

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INTRODUCTION

The premise of this book is my firm conviction that advancement of all sciences that owe their foundations to the cognitive processes depends on an extension, a deepening, and an exactness of description within the cognitive dialogue between the perceiver and objective reality. This tenet is well served by the choice of topics highlighted in the chapter titles in this book: (1) *A New Theory of Time*, (2) *Events and Observability*, (3) *Multidimensional Units and Languages: Verbal and Nonverbal Communication*, (4) *Judgment Formation and Problems of Description*, and (5) *Memory and Perception: Some New Models*, (6) *Stochastic Models of Expertise Formation, Opinion Change, and Learning*.

From the content of the chapters it may be seen that the book puts stress on concepts such as time and observability underlying all cognitive processes, as well as processes that constitute fundamentals of expert systems (Chapters 2, 3, and 4). The aim of Chapter 6 is also to more deeply connect the cognitive sciences with the topics of expert systems and AI. One can hope that such an approach will—to some extent at least—allow us to overcome the difficulties in communication and conceptual incompatibility of the cognitive sciences and the dynamically developing AI field [for information on the latter see, e.g., Barr and Feigenbaum (1982), Heyes-Roth et al. (1983), Nilssen (1980), Pearl (1984), or Winston (1983)]. Formal semiotics and formal theory of actions [see Nowakowska, “Quantitative Psychology: Some Chosen Problems and New Ideas” (1983), and “Theories of Research” (1984)] constitute an important extension of the problem of representation of knowledge about structure and change of situation/object, and actions admissible for this situation.

Each chapter presents a new theory or set of theories. Each begins with an extensive introduction outlining the theory’s content and its relationship to other theories. At the same time, to facilitate reading, all formal considerations are accompanied by an intuitive informal explanation and most proofs are

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given in chapter appendices.

Extensive use is made of fuzzy set theory, which allows a more flexible and realistic description; throughout the text some foundational problems of this theory are shown. These problems are connected with the properties and distortions of judgment formation.

Chapter 1 allows relatively deep penetration into the process of observation, the problems of construction of such an abstract concept as time, and (among others) the reconsideration of James's concept of stream of consciousness. However, the crucial topic in this chapter is the distortion of time perception and the relationship between objective and subjective time. An explanatory concept used here is that of a pre-event (being a candidate for an event to be stored in memory) and the concept of a dynamic event-representation of an object (events on events) generated by the perceiver in the process of perceptual work.

Moreover, the boundedness of memory and attention, which leaves many events outside the scope of consciousness, leads to subjective discontinuity of time and space caused by competition of internal and external processes in consciousness. The principle of semantic continuity allows us to overcome the discreteness of consciousness and to pass relatively smoothly from one semantic system to another. Theory of time is, in fact, an extension of the theory of measurement [for information about this important domain of mathematical psychology, see, e.g., Nowakowska (1983)], to the problems of time, where such considerations were simply absent. The theory of time combines in one formal system the problems of objective and subjective time and memory. This is a theoretical novelty in measurement theory, being the first analysis of its kind in the literature. One can expect that further development of the theory of measurement will go towards construction of new class of models that are not only descriptive but also explanatory, thus bringing it closer to cognitive processes, and allowing us to rely less on physical models. The notion of time is of fundamental importance not only for measurement from the theoretical, philosophical, or physical point of view, it is also crucial for AI (simulation of cognitive processes), mathematical theory of programming (restrictions of satisfiability and truth in time), and in studies of structure and coding of information, especially for the new generation of super fast computers for which information is to be coded in molecular structures. The chapter also contains a discussion of other theories of time, mainly causal in nature.

In the social sciences one often deals with changing objects of a fuzzy character (e.g., attitudes, inflation); the fuzziness may concern either the spatial or temporal boundaries of the object or even its definition. The theory of such objects, as well as their observability and the related concept of a fuzzy event, are introduced in Chapter 2. The latter is different from the concept of event

studied in fuzzy set theory (Zadeh, 1965) and in probability theory, in which the events are identified with subsets of the sample space. The basic notions in this chapter are those of preobjects, their temporal cores and carriers, as well as observability networks. They allow us to define the concept of an object and the concept of the separation of two objects. Of crucial importance here are the considerations of restrictions of observability, in particular the constraints on joint observability, which are often overlooked in cognitive, behavioral, and social sciences. Thus, two attributes may be observable, but not jointly; that is, if we observe one of them, the other cannot be observed. We have to decide then what to observe, and pay for it by being unable to observe the value of the other attribute. This is common in physics, biology, etc., but it also appears in cognitive and social sciences, when the observation may modify the subject irreversibly. In other words, the choice of what to observe has some immediate consequences on what one does, by limiting the scope of legitimate inference.

Various types of observability constraints, as related to fuzziness or physical impossibility of joint observations, are analyzed. Also considered are the effects of outside interference on observability, called *filters*, and the constraints imposed by the observer's choice of temporal patterns when taking observations, called *masks*.

The importance of constraints on observability reaches far beyond the obvious cases of measurement errors or grouping of data. The concepts introduced may have considerable usefulness in the social and cognitive sciences as a foundation for a formal theory of experiments. The most important contribution of observability theory, however, is the ontology of random fuzzy objects, which is encountered so often in the social and cognitive sciences. Some examples of such objects include "epidemics," "inflation," "human attitude," "intelligence," etc.

Theory of objects and observability, combined with theory of formal semiotics, may allow us to enrich, deepen, and revise the theoretical and methodological foundations of the social and cognitive sciences. Moreover, it may also be of importance for AI, in simulation of research. In systems theory, it allows us to introduce a new class of systems, namely, those of semirandom and random objects, with various kinds of distinguishability and changeability. Such systems may have interesting applications in physics (linear random systems, random fields, etc.), as well as in computer sciences and biology.

Chapter 3 shows how one can incorporate into one system a formal description of simultaneous communication events and actions occurring in everyday life. The concepts of multimedial fuzzy units and languages not only describe communication phenomena but may also be useful in modeling and simulation of some neuropsychological processes in the brain. Another

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important concept for the same purpose might be that of networks with randomly varying nodes and edges (appearing and disappearing, according to suitable stochastic mechanisms). For this approach, the reader is referred to Chapter 3 of “Theories of Research” (Nowakowska, 1984), where it was used to model social networks in science. This would allow simulation studies of knowledge acquisition and learning, in particular if one accepts a new learning model (shown in the last chapter), in which the increases in knowledge about a given topic occur at random moments in the form of enlightenments, not only during effective learning of a given topic but also during learning of some other topics. This happens because of the existing semantic relationships between topics, and because of delayed learning due to perseverance of previous topics in memory that are not sufficiently understood, as well as some tendency of restructuring, re-representing and re-interpreting of the perceived and learned material. The above ideas may lead to some new approaches in machine learning, dominated thus far by sequential models [see, for instance, Michalski *et al.* (1983)] and computer architecture.

In this chapter we consider not only the structural constraints (such as enforcing or exclusion) of these units but also their fuzzy semantics. For the multimedial languages, for example, one analyzes, among others, pragmatic semantics, that is, problems of expressibility of certain meanings in situations in which some media are excluded from use (the media in this case being verbal medium, medium of gestures, medium of facial expressions, etc.). These considerations are used later (in Chapter 5) for a heuristic model of memory, which introduces the notions of internal action languages.

As regards communication problems, one considers planning and realization of a unit in a given context by the sender, as well as expectations concerning kinds of units, from the viewpoint of the receiver, especially under temporal constraints.

The notion of a standard fuzzy unit is introduced, and the importance of particular media for a given meaning is analyzed through the concept of recognition weights (based on voting coalition theory). These recognition weights play an important role when the exposition time is limited.

As a result, the unit as a whole expresses various meanings in varying degrees, depending on the meanings expressed on particular media and the degrees of expressions of these meanings.

The meaning of a unit is treated as an invariant of a certain class of transformations, and composite meaning is obtained as a result of a certain semantic calculus, with operations such as supporting and inhibiting. This analysis is also applied to strings of units, especially those that appear in dialogues. The latter are treated in the last section of the chapter, with special emphasis put on the meanings expressed by nonverbal media.

At present, an increasing number of researchers appreciate the advantage of analyzing behavior in terms of strings of discrete units, in particular,

communication behavior. Chapter 3 provides not only a theory but also a convenient methodological tool for empirical research.

One of the most important media in communication is quite obviously the verbal medium. The psychological, logical, and linguistic analyses of various aspects of judgment formation and description are presented in Chapter 4. Emphasis is put on the role of ambiguity (and unavailability of the latter) connected with such properties of perception as the ability of discrimination and identification. It is shown how these properties of perception constrain the logical values such as truth, which lead to their uncertainty and vagueness.

The models of judgment formation are relevant for social sciences, linguistics, and fuzzy set theory.

The models of question answering show, among other things, those psychological mechanisms that are responsible for distortions of answers. These models allow for reconstruction of the statistical characteristics of answers in the population, in the sense of variability. This, in turn, leads to estimation of the magnitude of a bias. The models have been successfully tested empirically and are the first of this type in the psychological and sociological literature. For fuzzy set theory, they bring attention to certain important inherent cognitive problems concerning negative bounds on the possibility of removing uncertainty and vagueness. These bounds restrain to some extent the development of fuzzy set theory, especially its applications, and show the necessity of concentrating efforts on the foundational aspects of the theory.

Chapter 4 also deals with a theory of descriptions called *verbal copies*. The subject evaluates an object within its various semantic dimensions, that is, classifies it according to relevant categories, thus performing a multiple linguistic measurement [for the latter concept, see Nowakowska (1979d)].

The main problem analyzed here concerns the structural aspects of such descriptions and their relations to reality, especially truth (referred to as faithfulness, in case of fuzzy attributes) and exactness. This leads to exhibiting various cognitive limitations on descriptions, especially those connected with the choice of the language of descriptors.

For describing a dynamically changing object, the notion of generative verbal structures (verbal copies enriched by temporal and motivational variables) is introduced and connected with the algebra of goals and means [for a description of motivational linguistic variables, see Nowakowska (1973)].

The algebra of goals and means (Nowakowska, 1976a) allows us to analyze the attainability of composite goals (in this case, the descriptions of future states).

The study of composite descriptions leads in a natural way to theories of texts and knowledge. A very rich system of concepts is introduced for analysis of text properties, especially the semantic relations between the text parts.

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These relationships may be analyzed from logical, linguistic, and statistical viewpoints; in addition, a model for change of topics is introduced.

Among the many ways in which a text may be viewed, two are analyzed in more detail: as a sequence of responses to a hypothetical string of questions and as a representation of some body of knowledge. The latter analysis may be of some wider significance and applicability, since it combines not only the factual knowledge but also the evaluations of propositions as regards their credibility, possibility, and so on. The suggested theory of α -bility provides the rules of combining the degrees of credibility, possibility, and so on, of constituent parts of a text into an overall judgment.

The last section of Chapter 4 deals with the dynamics of discourses, that is, with the analysis based again on the algebra of goals and means. The latter leads to treating the generation of a discourse as a function of the planned composite goal. These considerations show, from a somewhat different viewpoint, the previously discussed topics of knowledge generation and structure.

Chapter 5 deals with certain important aspects of two closely interrelated psychological processes: memory and perception. Several models are offered, some treating these processes separately, some treating them jointly as two components of a larger process.

Regarding memory, the book offers some novel approaches that capture the effects of control of memory storage time. Generally, this model tries to reconcile two seemingly opposing facts: (1) that the process of information loss in memory (forgetting) is to some extent random and beyond conscious control and (2) that one may control memory storage by conscious efforts to remember given information, at least until a specified target time.

The model is based on the idea that in order to enhance the probability of remembering information at some future time one may simply increase the number of memory units that store this information (so to speak, "copy" the information several times).

The control of memory results from the operation of metamemory, which issues "metainstructions" concerning not the content of the message to be remembered, but the message itself. This idea of memory operation raises a number of interesting questions. It is clear that producing several copies of information will enhance the probability of remembering (existence of at least one copy at target time) if the processes of losing information are to some extent independent.

The models offered in Section 5.2 explore this problem. First, they offer two alternative mechanisms of "copying" (called *internal recalls*): one in which an internal recall produces an additional copy and another in which an internal recall causes doubling of the number of copies.

Regarding the process of losses, the assumptions cover the case of total independence as well as the case in which the process of forgetting is "self-

accelerating" (i.e., loss in one memory unit enhances the chances of loss in other memory units).

Another problem of considerable interest concerns optimization. Given the target time (when the information is to be recalled) and given a limitation on the number of internal recalls that one can make, the question arises of their optimal location in time. Here the analysis leads to some rather unexpected results, showing (among others) that the optimal placement of two internal recalls differs in essential aspects from the optimal placement of three internal recalls.

The model of memory with internal recalls is used in Section 5.3 to analyze the process of memory of sentences. Here the internal recalls are induced spontaneously by some of the subsequent words of the sentence (due either to the structure of the sentence or to some semantic relations between the words). The model offered explains the empirical data, which show the phenomenon of better recall of the initial and terminal words of the sentence.

The discussion closing Chapter 5 shows a heuristic dynamic model of memory (Nowakowska, 1981b; the first version of this model was presented in 1978 at the Berlin Symposium on Cognition and Memory) that uses the theories presented earlier in this book. Among others, crucial here are multidimensional units and languages and the algebra of meanings, which lead to parallel, distributive, and hierarchical concepts of memory.

It is worth stressing that this conception, in combination with that of metamemory determine the strength, direction, and horizon of storage, preceded by only a few years the actual interests of memory theoreticians in multidimensional units having internal structure and capable of simultaneous processing, as well as in control processes [see, e.g., Hinton and Anderson (1981)].

The notion of metamemory and multidimensional units may play a crucial role in artificial intelligence, where it may serve as a basis for the greatly needed model of the structural program of memory founded on new cognitive and economic principles.

One of the functions of metamemory may not only be the choice of horizon time, but also the degree of faithfulness and exactness of represent of the object in memory.

The novelty of the dynamic model of perception lies in introducing the models of some basic mechanisms and in treating the process of perception as a mixture of these mechanisms. Additionally, it assumes partial control over the perceptual process, and, moreover, it is based on the concept of an event-representation of the object formed in the perceptual work of the eye. The basic unit of perception is a glance, which involves both jumping and fine eye movement.

The models of various perceptual mechanisms complement the more global approach to perception and recognition in Chapter 3. Four main