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COGNITION, SEMANTICS AND COMPUTERS

Marco C. BETTONI *

Models of cognition and language currently in use as frameworks for computer applications present a clear disequilibrium: they neglect productive mental activities, as for instance synthesis, and over-estimate receptive ones, as analysis. The paper focuses on the Kantian concept of object-synthesis as a basic mental mechanism and underlines its importance for an equilibrated model of cognitive processing. Integration of the Kantian approach with Ceccato's model of mental operations could allow to implement synthetic operations in computer applications. A syntactic parser (von Glasersfeld and Pisani, 1970) which implements Ceccato's approach to cognition, semantics and linguistics is reproposed to the attention of AI researchers: it could be used as a basis for a modern implementation of object-synthesis in knowledge representation and natural language processing.

1. Introduction

> Denn wir haben es mit einer natürlichen und unvermeidlichen Illusion zu tun,...
>
> Immanuel Kant

This paper is about knowledge and language processing in the human mind. Its goal is to sketch a framework for the study of cognitive processes, that could be used to improve computer applications in knowledge representation and natural language understanding.

Much of what will be presented here is a speculation about a theory yet to be developed: thus, my approach will be rather to elicit intuitions than to present definitive assertions.

Why does Artificial Intelligence research face so many troubles and why does it fail to obtain the expected results in such important fields as knowledge and language processing as well as in less important ones, like chess playing?

In my opinion one of the crucial reasons is that cognitive science in its investigations on human mind is giving too much attention to what I call the *receptive* (passive) aspects of mind and therefore neglects what I call the *productive* (active) aspects of mental mechanisms.

* Author's address: M.C. Bettoni, Institute for Methods and Structures, Universitätstraße 17, CH-8006 Zürich, Switzerland.

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As a result, we have a deep disequilibrium, a strong deformation in all the currently used models of mental processing. This disequilibrium is also transmitted to the frameworks currently in use for the development of knowledge and language processing in the computer. The framework that I am going to present here is a first attempt to establish the needed equilibrium. Particularly, I want to show which are these *productive* aspects which have been neglected up to now in the leading models of mental activity and why they are so important.

At the same time I hope to draw the attention of AI to existing approaches, namely by Immanuel Kant and Silvio Ceccato, which could be used to build the foundations of a *productive* view on mind. It is by integrating these two approaches as well as by connecting them to the work of Maturana and Varela (1980), Piaget (1967), von Glasersfeld (1987), Winograd (1983), Schmidt (1982) and others, that modern studies of the cognitive processes could be equilibrated and better results in the fields of knowledge representation and natural language processing could be obtained.

2. Productive mind and receptive mind

What do I mean by 'productive' aspects of mind, what is precisely being produced and why are these aspects so important? To explain this I begin in this paragraph by presenting three examples and a block diagram resuming them.

2.1. Synthesis

A first example of a productive view on mind can be found in the famous, nearly 2,500 years old homo mensura fragment by Protagoras (Diels (1952: 263)), usually translated with 'Man is the measure of all things'. Commentators have not yet come to an agreement (!) about the meaning of the sentence nor of its components (Cole (1972)), but I suggest that nevertheless we can use the sentence in the following way: 'Any individual is the measure of all the pieces (... ...) of knowledge in his mind'. Now the crucial point remains the meaning of this 'is the measure'. Here we can make a huge jump of nearly 2300 years up to the XVIIIth century and find in the *Critique of Pure Reason* the following sentence by Kant:

> 'Hitherto it has been assumed that all our knowledge must conform to objects. But all the attempts to establish a priori something about objects by means of concepts ,..., have, on this assumption, ended in failure. We must therefore make trial whether we may not have more success ... if we suppose that objects must conform to our process (faculty) of knowing.' (B_ XVI)

Kant's suggestion to suppose that objects must conform to our process of knowing could also be used as a suggestion for the meaning of Protagoras' expression 'is the measure', if we substitute 'objects' with 'pieces of knowledge'.

This would lead to the following use of the sentence: 'All pieces of knowledge in the mind of any individual must conform to the process of knowing he performs. And if this is the case, then we can also say that the person carrying out those mental processes is 'the measure' of all the pieces of knowledge he obtains'. The question is now in which way objects or pieces of knowledge can conform to the process of knowing. Kant's solution, 2300 years after Protagoras, is that objects are constituted in the mind and this is of fundamental importance for a model of mental activities emphasizing productive aspects. Notice that in this case we have two classes of objects: the manifold of the physical situation ('*unbestimmt*') and the objects we constitute in our mind ('*bestimmt*'), which can also be called 'objects-for-us'. In order to constitute these objects-for-us, the mind utilizes the operations ('*Handlungen*') of synthesis, which can be found at different stages in the process of knowing and are necessary to account for the unity of consciousness.

Kant gave much attention to synthesis and made it the central concept of his entire Critical Philosophy (Wolff (1973)). We shall see in section 5 which role the faculties of synthesis play in Kant's architecture of the mind. In section 6 we shall then consider the elemental forms of synthetic operations as they have been developed in Ceccato's operational approach to mental activities and partially implemented on computers about 30 years ago. I hope that we shall not have to wait for another 2300 years before some scholar will try to continue and develop Kant's and Ceccato's approaches.

2.2. *Attitudes*

A second example which is representative for the productive faculties of mind is the fact that any individual, when faced with a certain physical situation, has at his disposal quite a variety of responses.

Consider for instance a text in a book. The physical situation, that is the book, with its pages, and the pages with their black sequences (of characters) are the same each time we read the book. But the ideas, thoughts, feelings, reflections, etc. connected with the reading of that text can be different for the same reader, at different times. The same thing happens when many individuals are contemporarily faced with the same physical situation, as for instance in a concert, where the physical situation is given by the sounds produced. A measure of the physical properties of the sounds as pressure waves would show minimal differences throughout the concert hall, but how contrasting are the experiences ('responses') developed by the participants during the performance. The fact that the experiences of different participants can also be *convergent* (and this is apparent in communication) has diverted our attention from the fact that they are at the same time *divergent* to a high degree.

Which productive aspects of mind determine the variety of responses in reading and listening? Not only the faculties of synthesis, which can be used in different ways by each participant, but also other more general processes play an important role here, and among them particularly the faculty of any individual to vary its *attitudes*, to put forward a great variety of expectations, to produce anticipations and purposes. From a receptive point of view an attitude is a way to 'react' to situations, a kind of inertness, of dependence of the individual from the situation. But this is only one side of the coin. From the other side, from the productive point of view, an attitude is a way to go in search of something and hence it is based on independence and initiative.

2.3. Self-organisation and autopoiesis

Finally, a third example of productive aspects of the mind is what I call the *background* activity of mind, a part of which corresponds to the activity of the 'unconscious', as studied in psychology. We usually do not pay attention to the power of background activity although we continuously experience and use its results. For instance, we forget that many ideas rise up to our attentional focus during the day independently of what we are doing; we do not take notice of our ability to 'retrieve' a name minutes or hours after the question has been asked (for instance, the family name of Verdi's second wife, Giuseppina ...?); we do not ask from where the solution of a problem, which we could not find one or two days or perhaps months ago, has now suddenly reached the center of our attention (as Kekulé's benzene ring). All these experiences are results of a background activity, a most fascinating *productive* faculty of mind.

Background activity can be explained and studied through the results of researches like those by Piaget, Maturana and Varela concerning the biological and mental structures of cognition. *Piaget* has shown that the more general biological functions of a living system, like organization, adaptation and assimilation, conservation and anticipation, self-regulation and equilibration can all be found also at the cognitive level and that all play the same essential role there (Piaget (1967)). Every cognitive equilibrium, he says, involves the processes of assimilation and accommodation. Assimilation may involve an interaction only with *internal* elements, for example the coordinating of the total cognitive system with the subsystems of which it is composed (Piaget (1975)). This coordinating, which is an integration of subsystems into a whole and produces their assimilation to a common structure, is one of the main components of the internal self-organization of mind. Piaget has also pointed out that the main advantage of self-organisation (self-regulation) is that it can be controlled directly (Piaget (1979)), that is independently from external constraints: this is exactly what a productive mind needs in order to develop its initiatives.

Maturana and Varela have developed the idea of autopoietic systems as systems which continuously generate and specify their own organization through their operation as a machine producing its own components (Maturana and Varela (1980)). Applied to mind, this model means that the results of mental activity will contribute to modify the organization and components which previously produced them and will also contribute to specify them for new activities and for new results. In the autopoietic model, living systems do this in an endless turnover of components. Their nervous system is operationally closed (Varela (1987)), that is, they have no input or output of information. What reaches the system from outside is not information, but simply a perturbation which will be 'in-formed' according to the internal coherences of the system (see Kant's assumption that objects must 'con-form' to mental mechanisms).

All these results by Piaget, Maturana and Varela can be gathered together under the terms *self-organization* and *autopoiesis* and contribute to explain the more general mechanisms of the productive side of our mental system.

2.4. *From the manifold to the knowledge base*

In figure 1 I have on the left side collected the three productive functions of the mind discussed in the examples and on the right side suggested three corresponding receptive functions.

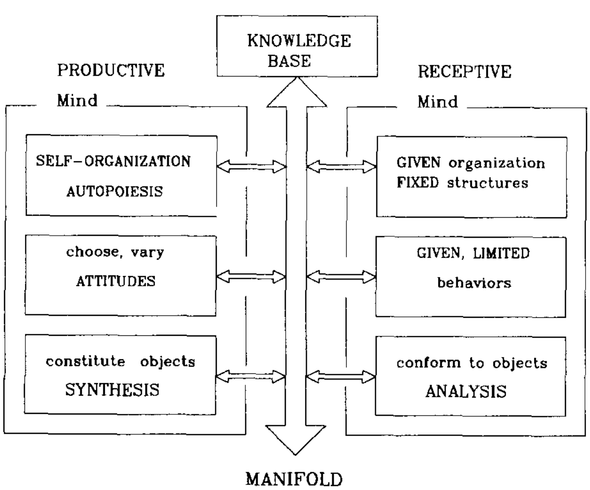

Fig. 1.

All the units are connected by a central way (bus-architecture) because I assume that mental activities are always obtained by a cooperation of the productive with the receptive functions (compare also B_74).

The term 'Manifold' at the bottom of the figure represents the operands which are influenced by the operating of the 6 units (a priori) as well as gradually processed in various stages up to the top where they finally become a component of the 'Knowledge Base'.

The 'traffic' on the bus-connection moves between all the units and the activities of all the units are coordinated. When a particular synthesis has to be performed in the unit labeled 'Synthesis', the choice could come from the unit 'Attitudes', which processes the goals for anticipations, expectations, etc.

These goals are themselves under the influence of the unit 'Autopoiesis' which, in its turn is under the influence of feedbacks from the Synthesis unit and from the other four units. This circularity of processing is a mechanism which at any moment allows the system to determine its next processing step: in this way there is no danger of infinite regression in the decisional hierarchy and no need for an independent regression-control with a break condition.

Through this circular organization, the 6 units are all contemporaneously contributing to the same mental process, and their contribution is equivalent and equilibrated. Unfortunately the contribution of the productive side to cognitive tasks has up to now been neglected. My aim in the next section is to show with some more examples the immense importance of the productive side and to suggest that we cannot obtain a viable model of language and cognition as long as we continue to neglect synthetic operations.

3. Synthesis of objects

3.1. Synthesis of what?

Look at a line in space. What do you have to do in order to perceive it? Is your activity simply a kind of mental picture-building, is it simply a mapping of the 'object' from outside to an internal 'replica' followed by a process of feature extraction?

My line of reasoning is that synthesis, which is a productive activity of mind, plays a main role in perception and in all the other cognitive tasks from the very beginning of the processing. It is synthesis which provides the ground on which analysis can work.

But of what kind of synthesis am I speaking? Synthesis is a general concept which can be used in a wide range of situations. Webster's Dictionary lists 3 senses and 5 subsenses (Webster (1984)). The sense in which I use 'synthesis' in this paper is more specific and is based on Kant's *Critique of Pure Reason* (I use here the German edition (Kant (1966)); translations are always by myself, with the help of the Norman Kemp Smith edition (Kant (1933)).

Hitherto scholars have not yet succeeded or not yet tried to use and further develop what Kant has written about synthesis. Sometimes Kant's concept of synthesis has even been ignored, as for instance by Russell in his *History of Western Philosophy* (Russell (1946)).

In my opinion we cannot understand the *Critique* at all without an explication of the concept of synthesis. And if we are able to design a viable model of Kant's view on synthesis, then we will also succeed in using it in current cognitive science.

The first definition of synthesis in the edition B of the *Critique* is as follows:

> '...the spontaneity of our thought requires that this manifold [the manifold of the pure "Anschauung" a priori] has to be first gone through, taken up and connected in a certain way in order to obtain a piece of knowledge out of it. This operation I name synthesis' (B_102).

We can find two important things in this definition. First the operand ('Stoff') on which synthesis operates is the manifold; this manifold can be either a priori (B_102) or empirical (B_103). Second, the result obtained by synthesis is finally a piece of knowledge ('eine Erkenntnis' in the German text).

It is important to understand that Kant is here merely introducing this concept and that he does this by a top-down approach, starting with a general definition. In the following he develops the concept in its particular features and shows that synthesis is performed at various stages of cognitive processing and that it deeply determines the stepwise procedure leading from the manifold to knowledge. Between each stage of the processing we have intermediate results among which one of the most important is the 'object-for-us', the constituted object. Objects are not produced as material entities ('dem Dasein nach' (B_125)), nor as mental replica of reality: they are constituted (made possible, a priori determined (B_125)) as mental constructs ('Vorstellungen') through the synthesis of the manifold which makes a '*Bestimmtes*' out of an '*Unbestimmtes*'.

Kant gives the example of a line in space (B_137/138). The line, as an object in space (a part of the manifold), is not produced by the mind, but in order to perceive it I must constitute it in my mind ('muss ich sie ziehen'), that is, I have to provide a certain kind of connection of the given manifold through the operations of synthesis ('muss ... eine bestimmte Verbindung des gegebenen Mannigfaltigen zu Stande bringen' (B_138)). Thus the line is not completely given, only the manifold is given, and we have no object in our mind without our own synthesis of it. Before we operate on the manifold there will be no 'line-for-us'.

Kant underlines in the following way the productive aspect of the process giving connection:

> 'Connection does not ... lie in material objects and cannot be extracted from them through perception and so first taken up in the *Verstand*; on the contrary, it is alone a performance of the *Verstand*, which itself is nothing but the faculty of connecting a priori ...' (B_134/135).

We can thus resume as follows the ideas sketched here: the operations of synthesis perform connection and the result is an object as mental construct, an object-for-us. Thus, the synthesis we consider in this paper has always to be understood as a *synthesis of objects-for-us* (objectivity of mental activity). This synthesis provides the ground on which analysis can begin its work of 'objective' feature extraction (separation) and 'objective' classification, in accordance with Kant's view that 'Where the *Verstand* has not previously connected, it cannot separate' (B_130).

3.2. The over-estimated faculty of analysis

Despite the immense importance of the mental process of object-synthesis, the Kantian approach has not yet been further developed in this specific direction. Instead, his work on synthesis has been generally criticized (Adorno (1966)) or developed in other directions (Cassirer (1964)). At the same time the main research efforts have been concentrated on the faculty of analysis.

In recent AI research the need for other approaches has been gradually recognized in empirical applications, but in theories and frameworks emphasis is still being laid on the faculty of analysis. How can this situation be explained?

First of all, it is hardly surprising if we consider that the process of analysis is often the final and conclusive stage of a first rough object-synthesis process. Kant has described this as follows:

> 'The synthesis of a manifold (be it given empirically or a priori) produces initially a piece of knowledge, which may, indeed, at first be crude and confused, and therefore in need of analysis.' (B_103).

Other reasons for the over-estimating of the faculty of analysis are deeply connected with our biology and culture. Aristotle gives an example of one of them in the beginning (book A) of his *Metaphysics* (Aristotle (1975)) where he states that people are fond of perceptions, and particularly of that kind of perception which is obtained through the eyes. In his opinion the reason is that visual perception enables us, more than other faculties, to increase knowledge and that it makes many differences 'apparent'. This identification of knowing and seeing was still widespread in Kant's time. He set himself against this theory (Wolff (1973)) and proposed that the given manifold obtained thanks to our receptivity must be *synthesized* to become knowledge (A_97–104). But the illusion continues to exist in our days.

It is common among people and among empiricists as well as among AI researchers to think that viewing an object under optimal conditions of background, position, light, etc., mapping it to an exact internal representation and selecting features from this internal 'replica' produces perception and knowledge. This way of thinking can be explained as the consequence of the important mechanism of *convergence*.

A first kind of convergence takes place when two persons face the same physical situation and their aim is to understand one another. In this case they try to maximize perceptual convergence and to minimize divergence in the mental results of their individual processing. The consequence is that in their experience attention is being focused on convergence (although divergence is also present).

Now, when they combine the given common physical situation with the experience of convergence, they come to the conclusion that the reason why they both converge in their results lies in the fact that they both *extract given features* from the common and unique given situation. And reversely, when their results diverge, they ascribe this to the fact that one of them is performing an 'adequate' extraction of the given features whereas the other is making errors.

These conclusions seem to be viable for 99% of daily life situations and the remaining 1% which cannot be explained in this way is ignored, so that doubts do not have any chance to survive.

The importance given to analysis is also connected with the study of our faculty to make models of physical situations, the so-called 'internal models of the external world'. In these studies scientists since Aristotle assume that there is a faculty, called 'abstraction', which plays the main role in modeling. In the classical and in many of the current approaches this faculty allows a person to separate, to retain relevant features and to remove or suppress irrelevant ones from a set of *given features of a given object*. Aristotle himself puts the basis to his view in the following terms:

> '...spoken sounds are symbols of affections in the soul, ...affections of the soul are the same for all; and what these affections are likeness of – actual things – are also the same.' (Aristotle (1979))

Today we can still find a similar way of thinking for instance in those well-known studies on the structure of matter which are based on the acceleration and smashing of particles. Moreover, analysis is here considered as a processing preceding abstraction and performing the identification or labeling of a feature as 'relevant' or 'irrelevant'. In this way analysis and abstraction are closely connected and both condemned to operate on a completely given external object from which the 'salient' features have to be extracted and composed into a model 'resembling' the object as much as possible.

What can be done against this natural and inevitable illusion? As an introduction to my solution of this problem I first discuss in the next section the importance of synthesis.

3.3. Importance of synthesis

The thesis of this section is that both the variety (flexibility) and efficiency of mental activity are based on the operations of object synthesis. The importance of synthesis is going to be explained hereby. For instance, the human ability in visual tasks to process complex scenes without processing all the individual details of these scenes (efficiency) suggests that object-synthesis plays the main role in such situations.

Imagine that you have a rendez-vous with a friend in a restaurant. You arrive there, enter the door and look around in the large room crowded with people. Suddenly you recognize your friend and move to reach his table. If this mental processing would be essentially based on analytic faculties, for instance on Descartes' 'dénombrements si entiers' (complete enumerations, Descartes (1960)) or on Adorno's 'Begriffslose, Einzelne, Besondere' (conceptless, singular, particular; Adorno (1966)) or on other processes requiring primarily an 'adequatio' of the mind to the objects, then we would have to perform an endless number of operations at each perceptual task, for each 'object' in our perceptual field. I call this 'operational squandering'. We would never fulfil a task like the pattern matching described in the example as quickly as we usually do, if our mind would have to extract features from each object and to analyse them.

On the contrary, if the mental process is primarily based on object-synthesis (analysis can also take place, but only on the ground laid by synthesis), then we can crucially reduce the number of operations and hence the time needed to fulfil the task. I call this 'operational efficiency', an economical mode of operation which can be expressed by the motto 'operationes praeter necessitatem non moltiplicanda sunt'.

4. Object level and symbol level

An equilibrated model of the mind in which analytic and synthetic operations are balanced could improve our frameworks for the development of knowledge and language processing in the computer. Unfortunately, as I mentioned in section 3, scholars have not yet succeeded in profiting from what Kant has written about synthesis, the central concept of his *Critical Philosophy*.

But why is this the case? And is there a possibility to use the Kantian text in a way that could contribute to advance cognitive science and AI applications?

My argument in this section is that we can use Kant's contribution about synthesis if we distinguish between two levels of inquiry in cognitive sciences: the symbol level and the object level.

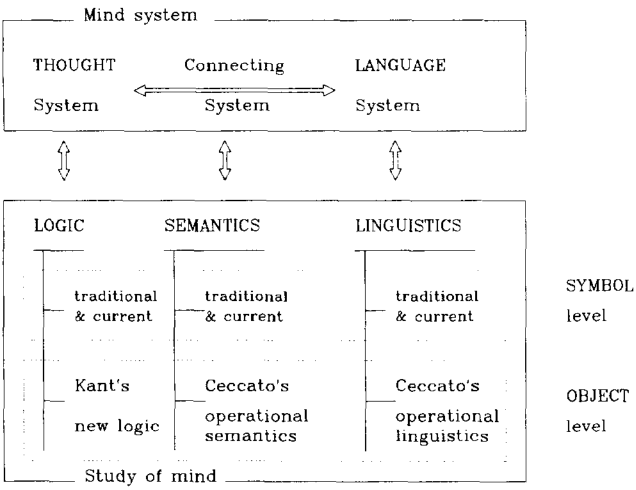

Fig. 2.

The symbol level collects all the modern leading theories about thinking and language, whereas Kant's theory together with other more or less ignored modern contributions (von Glasersfeld (1987); Ceccato (1961, 1969)) are to be collected at the object level. Theories at the symbol level are those which describe mind as a *symbol processing system* whereas theories at the object level deal with mind as an object-constituting system.

Hitherto, the theories on the symbol level have ignored or refused to accept those at the object level. My approach instead, is that both levels can and must equally coexist and cooperate in order to produce a viable model of mental activities. Their relation is such that the object level is the underlying level, the ground which has to be provided, before we operate on the symbol level. The symbol level presupposes an object level (B_682).

Figure 2 illustrates the components of my 2-level model for the study of mind. The box labeled 'Mind system' collects three of the main subsystems of mind: thinking, language and the system connecting them, a bridge between the two. The box below, labeled 'Study of mind' collects the three corresponding systems of inquiry which have as a matter of investigation the mental functions in the upper box: logic, as the investigation of thinking, linguistics as the investigation of language, and semantics as the investigation of the connection between thought and language, a bridge between logic and linguistics, with one bridge-head in the area of logic and the second in the area of linguistics.

For each science I have collected at the symbol level the leading traditional and current approaches (Fodor and Katz (1964), Johnson-Laird (1977), Winograd (1983), Minsky (1985), Pylyshyn and Demopoulos (1986), Crystal

(1987), Fodor (1987), Cercone and McCalla (1987)). Below them, on the object level, I have added Kant's new logic (Transzendentale Logik) and Ceccato's operational semantics and operational linguistics.

Terry Winograd, one of the leading experts in computational linguistics and cognitive science, has since 1972 developed a computational approach to language and cognition which gives a good example of what I mean is common in traditional and current approaches and causes them all to be considered at the symbol level (Winograd (1972, 1976, 1983)). In Winograd's opinion cognitive science is based on two assumptions:

> '1. The human mind can be usefully studied as a *physical symbol system*.
> 2. It is both possible and revealing to study the properties of *physical symbol systems* at a level of analysis abstracted from the physical details...' (Winograd (1976)).

He also states about cognitive and computer science, that:

> 'The same concepts of program and data that serve as a framework for building and understanding computer programs can be applied to the understanding of any system carrying out processes that can be understood as the rule-governed manipulation of symbols.'
> (Winograd, 1983)

Winograd's emphasis on mind as a system which manipulates symbols is the common denominator in traditional and current studies on mental activity.

My point now, is that although this view is correct and must take part in any model of the mind, it nevertheless fails to realize that studying processes which operate on symbols is not enough to explain the process of producing and comprehending sentences. This kind of investigation must be completed with and integrated into an equally important study of processes which constitute objects. For instance, the focus on cognitive structures in Winograd's procedural model of language where these structures are investigated only at the symbol level, needs to be extended to the object level.

What we need for an equilibrated model is also the study of processes which constitute objects, and hence a solution for the problem of 'Gegenstandsbezug' of symbols. Examples of such studies can be found in Kant's *Critique* and in Ceccato's model of mental operations (Bettoni (1985)). My suggestion is that Kant's system of the synthetic faculties of the mind could be integrated and completed with Ceccato's analyses of mental operations, which can be also understood as descriptions of the elemental, partial operations (Micro-operations) contributing to the main, complex operations of synthesis (Macro-operations).

The following sections 5 and 6 are conceived as an introduction to my attempt of integrating Kant and Ceccato; I hope to be able to suggest that such an integration is possible and that it could crucially contribute to equilibrating current models of thought and language as well as to improving computer applications based on such models.

5. Kant: Macro-operations of synthesis

In this section I first intend to sketch a system model of Kant's architecture of the mind. After that I shall focus on the operations of synthesis.

A cybernetic approach to Kant's *Critique of Pure Reason* shows that actually it is possible to redesign the Kantian text of the 'Transcendental Doctrine of Elements' into a system model in which mental functions are collected into units which in their turn are connected by channels. The operations of synthesis play a major role in the model and are collected into modules which appear in four of the five most important units. The model shows that the Kantian text can be used for an operational view on mental activity in which knowledge at any level (objects, properties, relationships, assertions, logical expressions, etc.) can be represented in terms of synthetic operations.

5.1. The cybernetic approach

My approach to the Kantian text is to be defined as cybernetic because of the following frame:
(1) I use an operational approach to mental activity based on Silvio Ceccato's 'TECNICA OPERATIVA' (Ceccato (1953, 1961)), one of the earliest approaches implemented on a computer (University of Milan (1961)).
(2) I look upon the mind as an Information Processing System (Bettoni (1985)) and upon cognition as a subsystem of mind.
(3) For the task of system identification of the mind system I apply a procedure of Systems Dynamics which emphasizes the importance of a qualitative approach (Profos (1982)).
(4) I make use of the fundamental postulate of NEW BIOLOGY (Maturana and Varela (1980), Varela (1987)) which assumes that our mind is operationally closed.
(5) I consider that the processes of assimilation and accommodation (Piaget (1937, 1967), von Glasersfeld (1974)) determine our choices between many possible operational sequences.
(6) As an overall criterion for cognitive activities I use that of 'VIABILITY' as it has been proposed by von Glasersfeld on the basis of RADICAL CONSTRUCTIVISM (von Glasersfeld (1974, 1977, 1981, 1987)): it determines the relation between mental constructs and reality.
(7) I consider autopoiesis and self-organization as over-all principles of the development of the mind.

Table 1
Substitutions developed for the architecture in figure 3.

Nr.	Kant's term	Symb.	Cybern. classif.	Substitutions and original text pagings [A..., B...]
1	ERKENNTNIS	ER	WHOLE OPERATOR	System of integrated mental constructs. [A_97]. Functional unit integrating mental constructs into equilibrated cognitive structures. [B_1, B_75, B_76].
2	ERKENNTNIS	Er	OPERAND	Integrated mental construct, piece of knowledge.
3	REINE ERKENNTNIS	rEr	OPERAND	Autonomously generated and integrated mental construct, independently from external disturbances [B_XVI, B_XVII, B_2, B_3, B_33].
4	EMPIRISCHE ERKENNTNIS	eEr	OPERAND	Integrated mental construct generated by functional units among which some depend on external disturbances [B_1, B_2, B_3, B_33].
5	ERFAHRUNG	Ef	OPERATION SEQUENCE	Sequence of operations (one of which depends on external disturbances) ending with (result) an integr. mental construct [B_1, B_147, B_196, B_218].
6	VORSTELLUNG	Vg	OPERAND	Mental construct [B_33ff., B_74ff., B_92ff., B_376].
7	VORSTELLUNGS-KRAFT	VK	OPERATOR	Functional unit collecting the functions of generating mental constructs [B_34, B_51, B_130].
8	VERSTAND	VD	OPERATOR	Functional unit collecting the functions of generating autonomously mental constructs, without depending on external disturbances. [B_75, B_129, B_134, B_135].

9	APPERZEPTION	AP	OPERATOR	Functional unit which selects and enables (= accompanies) the activities of the other units [A_ 94, B_132_ ff.].
10	APPERZEPTION	Ap	OPERAND	Result of the activity of the AP-unit [A_ 94, B_132_ ff.].
11	URTEILSKRAFT	UK	OPERATOR	Functional unit assembling pure and empirical mental constructs through the activation (application) of operations [B_ 93, B_102, B_104, _ ff., B_171].
12	KATEGORIEN	KA	OPERATOR	Functional unit assembling pure mental constructs obtained from the fBE-module and the pEK-unit [B_102_ ff.].
13	SINNLICHKEIT	SI	OPERATOR	Functional unit collecting also the function of generating mental constructs depending on external disturbances. [B_ 33, B_61, B_68, B_75].
14	produktive EINBILDUNGSKRAFT	pEK	OPERATOR	Functional unit autonomously assembling (by figurative operations) mental constructs from the AV-unit [B_150_ ff, B_ 204_ ff].
15	reproduktive EINBILDUNGSKRAFT	rEK	OPERATOR	Functional unit generating the connection of mental constructs form the AV-unit depending on external disturbances [B_150_ ff., B_ 204_ ff.].
16	ANSCHAUUNGS-VERMÖGEN	AV	OPERATOR	Functional unit modulating through space- and time-operations what comes from the EM-unit [B_ XVII, B_ 33, B_ 34, B_67].
17	REINE ANSCHAUUNG	rAn	OPERAND	Mental construct autonomously obtained by pure operations, independently from external disturbances [B_ 34_ ff.].

Table 1 (continued)

Nr.	Kant's term	Symb.	Cybern. classif.	Substitutions and original text pagings [A ..., B ...]
18	EMPIRISCHE ANSCHAUUNG	eAn	OPERAND	Mental construct obtained through pure operations performed on operands from the EM-unit (= perturbations) [B _ 33, B _ 34].
19	EMPFINDUNG	EM	OPERATOR	Funct. unit converting disturbances into perturbations [B _ 33, B _ 34].
20	EMPFINDUNG	Em	OPERAND	Result of the activity of the unit EM = perturbation [B _ 33, B _ 34].
21	ERSCHEINUNG	ERS	PART	Part of the manifold which will be synthesized in object-synthesis [B _ XXVI].
	Modules			
21	VERBINDUNG	VB	OPERATOR	Component of different functional units collecting the synthetic operations (composing, binding, connecting) [B _ 102 _ ff.].
22	VORSTELLUNGEN	* VO	OPERANDS	Component of different funct. units collecting operators to be sequentially processed in a VB-module (r = pure, e = empirical, k = categorial, p = productive, (*) = r, e, k, o). [B _ 33 _ ff.].
23	BEGRIFF	BG Bg	OPERATION OPERAND	Synthetic operation by a module [B _ 90, B _ 92 _ ff, B _ 102 _ ff.] The same synthetic operation, considered as a result, as a pattern.
24	formale BEDINGUNG	fBE	OPERATOR	Component collecting the space- and time-operations and the synthesis of apprehension for the conditioning of perturbations [B _ 37 _ ff.].
25	MATERIE	eMA	OPERANDS	Component collecting the operands (perturbations) to be sequentially processed in the fBE-module [B _ 33 _ ff.].

(8) In my architecture view on cognition I constitute and distinguish:

Operators – functional units or subunits, i.e. collections of functions (main and partial functions) and collections of operations;

Operations – activities of any functional units, mainly partial activities;

Operands – results of the activities of any functional unit or subunit;

Channels – links between operators on which operands are available as initial conditions or final states.

(9) In my process view on cognition I look for OPERATIONAL SEQUENCES as the collective work of connected functional units.

(10) Finally I put architecture and process view together into a whole to obtain a description of mechanisms, a system dynamics of mind.

5.2. A system model of Sinnlichkeit and Verstand

The model presented here is a first, rough prototype of a more comprehensive and refined model to be developed by future interdisciplinary research. I would like to emphasize that this type of research is still at its very beginning.

My system model is *qualitative* and not quantitative or computational, because before calculating something, we need to produce, to generate this 'something': this can be done only by qualitative models.

The text used here is a limited but fundamental part of the *Critique of Pure Reason* (Kant (1966)). Particularly important are the following parts:

– Transcendental Aesthetic	B_33 to B_73
– Transcendental Analytic	
Introduction	B_74 to B_88
Analytic of Concepts	B_90 to B_169

Please notice that, owing to the fact that translations of the Kantian terms are often misleading, I have decided to use the original German terms (see also Russell (1946)). In developing my system model, I have also used technical substitutions instead of philosophical interpretations. Therefore I do not claim to give in my model a description of what Kant 'really wanted to say'. I simply try to use his text as a technician, in a coherent and viable way (see table 1 for a list of the substitutions).

I developed my system model more in detail in another publication (Bettoni (1988a)); in this context my aim is to focus on the 4 modules for synthetic operations and to connect them with Ceccato's operational approach to the mind.

Let us have a look at the architecture sketched in figure 3. It presents some details of the two operators *Sinnlichkeit* and *Verstand*, which are the sources of '*Vorstellungen*' (B_74), i.e. of 'mental constructs' (according to my substitutions I do not use the word 'representations').

I have dissolved the units SI and VD by assigning a box to what Kant calls '*Vermögen*' or '*Kraft*' and by assigning a module to what is involved in specific operations, that which Kant calls '*Handlung*'.

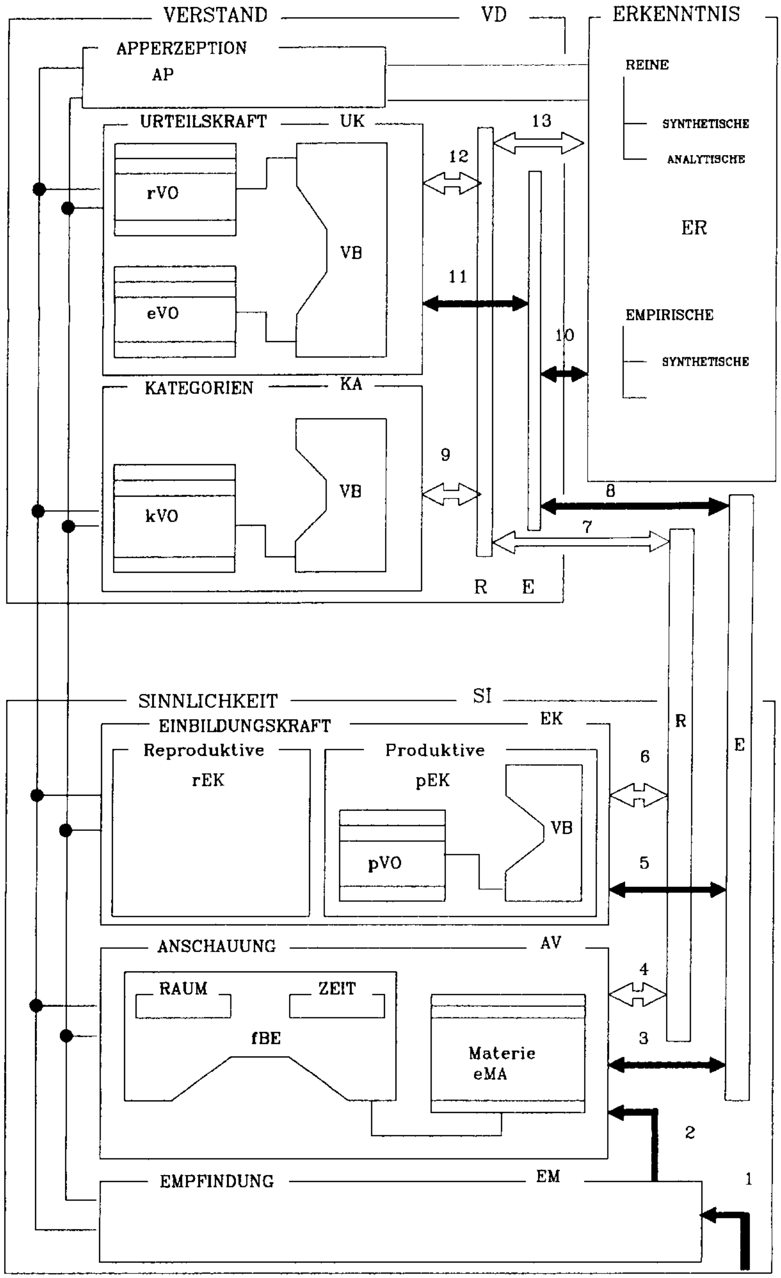

Fig. 3. Architecture of SINNLICHKEIT and VERSTAND.

There are two kinds of modules, a static and a dynamic. The static module is represented as a sequence of rectangular cells (circular buffer) and the dynamic module is represented as a box with a trapezoidal contour on the left side (like that used for ALU or arithmetic-logic units, in computer architecture).

A static module collects the operands of an operation, whereas a dynamic module collects the possible operations of one or more mechanisms.

In general I have used boxes for representing collections of functions (functional view, functions of operators). I have used modules, instead, for collections of operations and operands (operational view, activities of operators).

The unit AP is connected to each of the 6 other units by 2 lines: they allow AP-operations to 'accompany' any mental construct in SI, VD and ER, and contribute to implement the unity of consciousness.

The arrows and bars system – which connects with each other and with unit ER the 5 functional units EM, AV, EK, KA, and UK – is composed by 13 black and white arrows and by 4 parallel vertical bars (compare the bus-architectures in computer systems). The black arrows 1, 2, 3, 5, 8, 10 and 11 as well as the two vertical bars denoted by E, are the channels on which *empirical* operands are available, whereas the white arrows 4, 6, 7, 9, 12 and 13 as well as the two vertical bars denoted by R, are the channels on which *pure* operands are available. By these means we can clearly distinguish two kinds of operational sequences running throughout the system: *empirical sequences*, which run from unit to unit via the black arrows and *pure sequences*, which run via the white arrows.

5.3. System dynamics: From Empfindung to Erkenntnis

The dynamics of my system model consists in the collective work (co-operation) of the connected units (networks). There are many passages in the Kantian text which can be used as descriptions of operational sequences. My aim here is merely to exemplify how such sequences can be expressed as the run of a particular course through a network of my system model.

(*a*) *Example* 1

The *Critique* begins with the sentence (Introduction, B_1):

> 'There can be no doubt that all our knowledge begins with experience.'

and continues a few lines later:

> 'But though all our knowledge begins with experience, it does not follow that it all arises out of experience.'

This text can be mapped into the system model in the following way (use table 1 for my substitutions):
- any component of the system of integrated mental constructs is obtained by an operational sequence which started with operations performed on external disturbances;
- but though the operational sequence of any integrated mental construct started with such operations, it does not follow that the operational sequence is entirely composed by that kind of operations.

(*b*) *Example* 2

A critical passage in the *Critique* is the whole §10 beginning at B_102. Let us see the following passage at the end of B_104:

> 'What must be first given in order to make a priori knowledge of all objects possible is the manifold of pure *Anschauung*; the synthesis of this manifold by means of the *Einbildungskraft* follows as second ... The concepts, which give unity to this pure synthesis, and which consist solely in the *Vorstellung* of this necessary synthetic unity, perform the third step for the knowing of an existing object ...'

In my system model I describe this as follows:
- to obtain a pure integrated mental construct (piece of knowledge) we need first the synthetic operations of the module fBE (which condition the perturbations) alone, without operands from the unit eMA;
- next we need the synthetic operations performed in the unit pEK on the results of the first step which are collected in the module pVO;
- finally, the third step is performed on the pure assembly obtained from step 2, by synthetic operations which connect it to obtain an object-for-us related to the part of the manifold (object) involved in the process.

5.4. Four modules for synthetic operations

Any mental construct, or piece of knowledge, or object-for-us constituted in the system of figure 3 is obtained through operational sequences similar to those described in example 2 of section 5.3.

These operational sequences receive their inner coherence through the activity of unit AP which provides the unity of consciousness and coordinates the operations of the single modules.

In the dynamics of an operational sequence, the main role is being played by the following four modules (see also table 1, Nr. 22, 25):

I.	module fBE	in unit AV	(Anschauung)	= fBE[AV]
II.	module VB	in unit pEK	(prod.Einbildungskraft)	= VP[pEK]
III.	module VB	in unit UK	(Urteilskraft)	= VB[UK]
IV.	module VB	in unit KA	(Kategorien)	= VB[KA]

The first module, fBE[AV], collects two distinct groups of operations:
(1) *Space- and time-operations.*

These operations are what Kant calls "formal conditions for the possibility of Erscheinungen" (B_39, B_47). He considers space and time as a priori forms of our way to process perturbations (B_59). These operations are not synthetic.

(2) *Synthetic operations of* Apprehension.

These operations (*Handlungen*) are in Kant's terminology collected under the name 'Synthesis of the *Apprehension*', so called because by means of this synthesis the manifold of an empirical *Anschauung* can be run through and held together ('*das Durchlaufen*' and '*die Zusammennehmung*') in a single mental construct ('*in einer Vorstellung*', A_99, B_160).

The second module, VP[pEK], collects the operations which can be performed on a given manifold (either pure or empirical) which is an operand obtained from the first module fBE[AV].

Kant collects these synthetic operations under the term 'Synthesis of the *Einbildungskraft*'; their result is always the constitution of an 'object-for-me' ('*Object für mich*', B_136ff., §17). If the operand of the operation is pure (pure manifold) then we have a 'pure synthesis' and hence we obtain a 'pure object'. If conversely the operand is an empirical manifold, then we have an 'empirical synthesis' and obtain an 'empirical object'.

The individual synthetic operations ('*Funktionen*', B_93, B_104) which provide this constitution of objects are called, with Aristotle, categories, or pure concepts of *Verstand* ('*Kategorien*', '*reiner Verstandesbegriff*', B_104, B_105).

There are two kinds of categories, the primary pure concepts ('*Stammesbegriffe*, B_107) and the derivative pure concepts ('*abgeleitete*', B_107). Kant provided a list of the primary concepts in B_106. About the investigation of the derivative concepts he remarked that 'I reserve this supplementary work for another occasion' (B_108).

The third module, VB[UK], collects the synthetic operations which can be performed on the mental constructs, on the objects-for-us ('*Vorstellungen*') obtained in the previous steps.

Kant assigns these synthetic operations to the faculty of the *Verstand* to produce judgments ('*Vermögen zu Urteilen*', '*Urteilskraft*', B_94ff., B_169).

All judgments, he maintains, are functions of unity among our mental constructs [B_94]. This means that the individual operations which are performed in the unit UK always synthesize a judgment (unity) out of different operands (mental constructs, objects-for-us, concepts). In one of the most famous passages of the *Critique*, Kant states that the individual synthetic operations which provide this judgment-synthesis are the same as those which provided the object-synthesis:

> 'The same function which gives unity in a judgment to various mental constructs also gives unity to the mere synthesis of the mental constructs of an ANSCHAUUNG; its general name is pure concept of VERSTAND.' (B_104/105)

In another important passage, Kant maintains that any act of synthesis, also those which make perception possible through *Apprehension*, must be performed through the synthetic operations called categories (B_161).

This leads us to the fourth module, VB[KA]. I have introduced this unit as the operator which provides the generation of all those synthetic operations which are active in the other three modules, that is in fBE[AV], in VB[pEK] and in VB[UK], where they provide the synthesis of the manifold, the synthesis of objects and the synthesis of judgments respectively.

This is all I have hitherto obtained from the Kantian text about the four modules of synthetic operations. Although it is only a rough sketch, we can nevertheless see that Kant develops the operations of synthesis at a general level, that is, he described main operations (acts), which are complex structures consisting of basic, elemental operations.

Now, what about these basic operations? As we are going to see in section 6, an answer to this question can be obtained from the work of Silvio Ceccato.

In order to prevent confusion between the two kinds of operations, the complex and the elemental, I here introduce two specific terms: the term MACRO-operations to name the complex synthetic operations discussed by Kant and the term MICRO-operations to name the elemental synthetic operations described by Ceccato.

6. Ceccato: Micro-operations of synthesis

Which are the basic, elemental operations of object-synthesis, judgment-synthesis and manifold-synthesis? As I have anticipated in section 5, an answer to this question can be obtained from Ceccato's investigations on mental activities (Ceccato (1964/1966)).

6.1. Producing thoughts

To begin with, let us consider the following piece of a longer thought: '... element and structure ...'. The basic structure of thought, according to Silvio Ceccato is always a triad composed by two terms bound together by a binder (Ceccato (1961, 1967)). A triad has a characteristic dynamism, an order of operational precedence in that the first term, or first mental construct (Mc1) is

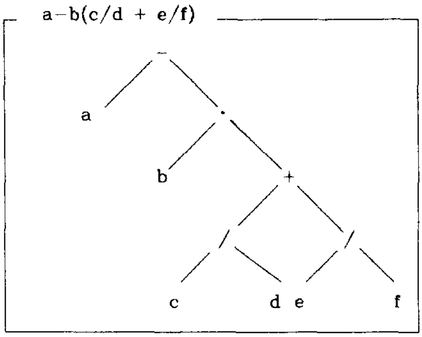

Fig. 4. Binary tree in algebra (from Knuth, 1973).

the first in time to be constituted (or activated) and is then held present (active) during the constitution of the binder, which in its turn is held present during the constitution of the second term, or second mental construct (Mc2). Among the best ways to represent this triadic model are in my opinion the *binary tree* structure and the time diagram.

Figure 4 introduces the kind of binary tree that I am going to use. This kind of tree is in use both in mathematics (Bronshtein and Semendyayev (1985)) and in computer science (Knuth (1973), Aho et al. (1986)), whereas the binary trees applied in linguistics are similar only in appearance. The difference is actually fundamental; in fact, the trees used in linguistics contain mental constructs only in their terminal nodes, that is in the nodes which have no children nodes. In the other nodes they merely contain syntactic classifications (Winograd (1983: 78)). Instead, the trees which I am going to introduce here contain mental constructs (objects-for-us, etc.) constituting thought in each one of their nodes: in the root node, in the common parent and children nodes and in the terminal nodes.

In order to prevent confusion between the two kinds of binary trees, let me introduce the name 'binary object-tree' for my trees. Moreover, because each object-for-us, each mental construct is the result of mental operations, the same tree can also be called 'binary operational tree', if we put the emphasis more on the operational point of view.

Figure 5 shows a general triad represented as binary object-tree and as time diagram.

Figure 6 shows the triad in the particular case of the thought 'element and structure'. In the notation Mc1[element], B[and] and Mc2[structure] the markers Mc1, Mc2 and B represent mental constructs, whereas the words in square brackets are the name which will designate the constructs in the following step at the level of language; for the moment, at the level of thinking, the constructs are not yet designated and for this reason their names are put in square brackets.

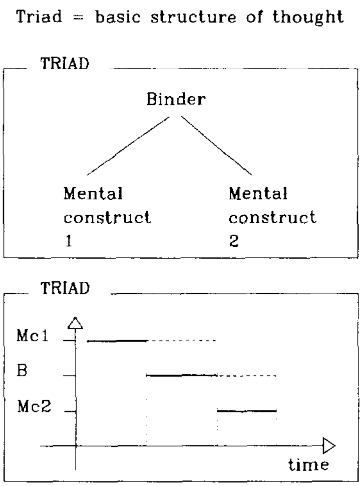

Fig. 5. Binary object-tree and time diagram for a triad.

The triad can take part, as an element, i.e. as a first or second term or even as binder, in the construction of a complex triadic network. For instance, in the thought 'The concept of element and the concept of structure ...' we have the triad composed by Mcl[the], Mc2[concept] and B-097 (= binder number 097, see below) which appears twice as an element in the two triads with the binder B[of].

The binder B-097 exists only at the level of thought, but has no corresponding individual term at the level of language. The number '097' comes from a table collecting the most important binders, developed by Silvio Ceccato and his group at the University of Milan (Ceccato (1967)).

6.2. Connecting thought and language

But let us see in more detail how thought and language are connected in the model developed by Ceccato and his group.

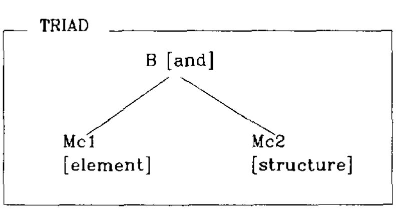

Fig. 6. Binary object-tree of the thought '... element and structure ...'

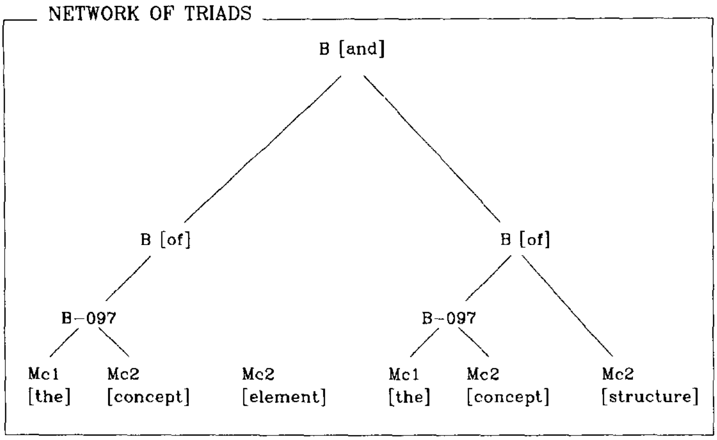

Fig. 7. Binary object-tree of a complex triadic structure.

The starting point is the triadic structure of thought. When we express a thought we indicate, for each triad composing it, which are the particular three elements of the triad and also which of the three functions each element performs: whether the function of Mc1 (first mental construct) or of Mc2 (second mental construct) or of B (binder). This means that to connect the dynamism of thought with that of speech, six indications must be provided in language, three for the particular things put into combination and three for the three possible functions carried out. But where are these indications in the case of the sentence 'The concept of element and the concept of structure...', which expresses the thought represented as a complex object-tree in figure 7?

The word 'the' indicates one of the three components of the first triad and its function as Mc1 (as first term), as well as the second component and its function as a binder. This means that four of the six indications are already provided by 'the'. The word 'concept' finally indicates the third component of the triad, providing one indication which brings to five the total number of indications explicitly provided through words. The sixth indication is implicitly provided by the fact that the triadic structure is fixed: when the three components which have to be combined have been indicated, the indication of the function of two of them implicitly reveals which function is left for the third.

6.3. Constituting the components of thought

Let us go back for a while to thought. We have assumed the existence of three kinds of elements as pre-existing the triadic assembling process and labeled them with the markers Mc1, Mc2 and B.

But where do they come from? Ceccato and the Italian Operational School proposed to study even these components in terms of operations, and developed a model whose mechanisms constitute all the elements Mc1, Mc2 and B of any thought by combining operands through different operations. The crucial point is here that, like the building bricks of a house, these operands are all the same and we can obtain different elements Mc1, Mc2 and B merely by varying the operations performed on the building bricks (Ceccato (1955, 1958, 1961)).

The basic structure of the elements Mc1, Mc2 and B, like for thought, is a triad. This triad is composed by two terms combined by an operation. Because its role is to constitute the individual elements of a thought, I propose to call it 'constituting triad' or C-triad. Its dynamism is analogous to that of the triad described as the basic structure of thought, whose role was to assemble the individual elements of a thought (assembling-triad or A-triad). Exactly like in an A-triad, also in a C-triad the first term, or first mental construct is the first in time to be constituted (activated) and is then held present (active) during the performance of the connecting operation, which in its turn lasts until the constitution of the second mental construct is concluded.

The binary operational-tree and the time diagram can be used for the C-triad in the same way as for the A-triad. As an example let us see how the component 'structure' in the thought '... element and structure ...' is constituted.

I shall first describe the binary operational-tree and then explain its components. As represented in figure 8, we have a triad composed by:
- the subtree Cs1[relation]
- the combining operation C3⟨feedback⟩
- the subtree Cs2[unity].

The complete triad is then composed by:
- the subtree Cs1[relation, C3, unity]
- the combining operation C2⟨parallel⟩
- the subtree Cs2[object].

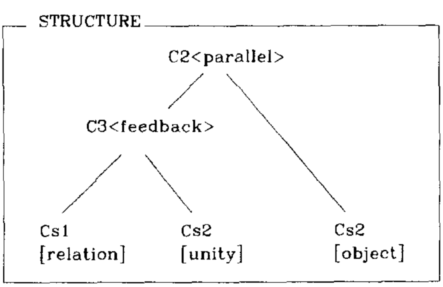

Fig. 8. Binary operational-tree of a mental construct designated 'structure'.

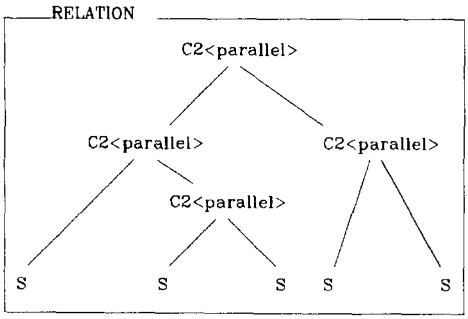

Fig. 9. Binary operational-tree of a mental construct designated 'relation'.

The components of this operational-tree are of two kinds:

(1) operations: represented by the letter C (for combining) followed by the number and by the name of the operator in angled brackets: $Ci\langle operation\rangle$, $i = 1, 2, 3, \ldots$

(2) operands: represented by the letters Cs1 or Cs2 followed by the name used to indicate them in language enclosed in square brackets: Cs1[name] = 1.operand, Cs2[name] = 2.operand

Concerning the operations, I have described elsewhere (Bettoni (1987)) that in the simplest model we can assume three kinds of operations: C1 = serial, C2 = parallel and C3 = feedback.

Concerning the operands, we can now introduce an additional fundamental result derived from the work by Ceccato and his group. First, there is a simplest operand, indivisible (atom), which is the only building brick of any subtree, i.e. the only terminal node and is represented by a capital S. Second, any operand of a complex C-triad is itself either a C-triad or a terminal node S.

Let us see this in the case of the subtrees [relation], [unity] and [object] which compose as operands the tree [structure].

Figure 9 shows the binary operational tree of the operand [relation]: it represents the synthetic micro-operations which constitute the concept 'relation' in our mind. The first operation consists in the connection of two S-terminals (two identical atomic operands); then follows the addition of another S-terminal, with the same parallel operation C2 and the composition of another pair of S-terminals; finally the two subtrees, the left one and the right one, are composed into a whole by the fourth operation. The resulting structure is what represents in our mind the kernel of our concept of 'relation'.

The concepts of 'unity' and 'object' can be described in the same way, and also a great deal of other concepts which are primary to any construction of objects-for-us, of judgments, of properties, of assertions etc.: the reader is referred to Bettoni (1987, 1988b) for a more detailed discussion of these issues.

6.4. Towards a computer implementation of object-synthesis: the Multistore System

The Multistore System is a parser which was developed in the course of a research project concerned with automatic analysis of natural language sentences (von Glasersfeld et al. (1965–1966), von Glasersfeld and Pisani (1970)).

The theoretical basis of this research project was Ceccato's approach to language and thought processes (Ceccato (1953, 1961, 1965)) so that the implementation of the parser contains many of the basic concepts which in Ceccato's approach explain the constitution of thoughts in terms of mental operations. For this reason I suggest that the Multistore System could be used not only as a parser but also as a basis for a modern computer implementation of the operations of object-synthesis and of more general productive mental activities. Let us see briefly the principle, the components and the procedure of the Multistore System (MS).

(a) Subsystems of MS

The first subsystem of MS is a collection of binders, the operations by which two operands are connected to obtain a triad (see section 6.3).

The second subsystem of MS is a collection of vocabulary items characterized in terms of their capacity to function as 1.operand (Mc1), as 2-operand (Mc-2) or as binder (B). This specification is obtained by assigning to each item an index which encodes the functions they can fulfil.

The third subsystem of MS is a collection of rules through which triads can be characterized in terms of their capacity to function as 1.operand or as 2.operand. These rules for triads are necessary because after two terminal operands have been composed into a triad by a binder, the resulting structure can itself become an operand of a next binder and the triad produced by this binder can in its turn become an operand of a new binder, and so on, with each new binder in the nodes of the three structure (Knuth (1973)).

The fourth subsystem of MS consists of the collection of ad hoc rules concerning for instance the processing of idiomatic phrases, the parsing of sentences which, although expected to become longer, do not continue, and other similar peculiarities of natural language.

(b) The main design principles of MS

For fully operational implementation of the parser in an experimental English sentence analyzer, the basic problem was that a parsing procedure running through the four subsystems would have required a very large amount of operations, if operative data would have been kept on secondary storage devices (magnetic tapes or disks).

In order to keep within reasonable bounds the processing times involved in a matching procedure, von Glasersfeld and Pisani decided to step out of the general trend in linguistic computer applications based on the use of secondary memory. For their programs and operative data, they decided to keep every operational path in the main memory (primary memory). This memory device has the advantage that its locations can be directly accessed by the instruction set of the central processing unit (CPU), without intermediate programs: so the access time is very low and information can be written into or read from the memory at a higher rate (access rate) than from secondary memory.

This use of the main memory for all the operative data, which was unique at the time, sprang from the assumption that the development of computers would lead to gigantic main memories and that real-time processing of linguistic tasks could be attained by adequately structuring the use of the main memory, rather than by using large but slower secondary memories.

The MS, in order to make the single matching operations in the main memory as fast as possible, avoids any shifting of the data involved, reduces the scanning to a small section of addresses for each item and eliminates the searching of lists. This is achieved by structuring a portion of the main memory, called the MS-Area, in such a way that data involved (for instance the binders of a triad or complete networks of triads) have a fixed sequence of addresses.

The structuring principle of the MS-Area is based on the same concepts of 'triad' and of 'network of triads' which have been previously presented in sections 6.1, 6.2 and 6.3.

(*c*) *Output of MS*

When the parsing of a sentence is completed, the output phase is reached.

The primary output consists of a graphic representation of a binary tree structure. In the examples given in the paper, which were taken from original computer outputs, instead of the commonly used slanting branches, the tree structures are represented by rectangular branches, which were less troublesome for on-line printers at that time.

Figure 10 reproduces the binary tree of example IV_a given in the paper (von Glasersfeld and Pisani (1970: 80)). I have merely reintroduced the slanting branches and added the markers Mc1, Mc2 and B in accordance with the principles previously discussed in sections 6.1 and 6.2. The numbers 2050N, 0247E, 2570N and 5010N specify the 4 binders of the network. They are taken from a list of about 350 binders which were available in the system. Only one of them is indicated by a specific word (explicit binder) whereas the other three do not have a word of their own in English (implicit binders).

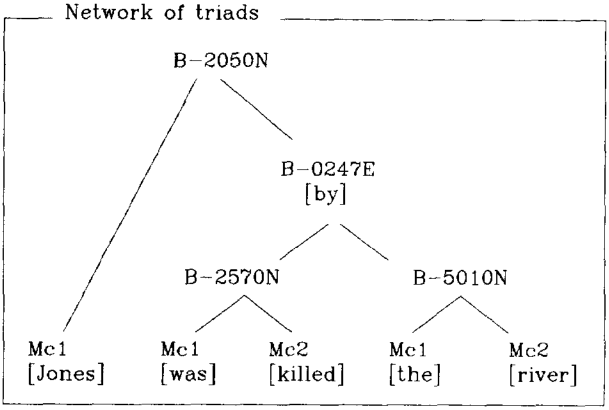

Fig. 10. Binary object-tree from a computer implementation (von Glasersfeld and Pisani (1970)).

(d) Technical data of MS

The size of the MS-Area implemented in the second version of MS at the University of Georgia, Athens, can be visualized as a rectangular area structured in 528 columns by 330 lines, for a total of 174, 240 8-bit bytes.

The entire system, including all accessory procedures for idiomatic phrases and special linguistic rules, buffer area for word input and complete program, occupied approximately 190[K bytes] of the IBM 360/65's main memory (capacity: 500 K bytes) and its programs were mainly written in machine language.

The system operated with some 350 binders (1.subsystem) and 300 rules (3.subsystem), accepted sentences up to 16 words long and required an average processing time of about 0.2 [sec/word] for the complete parsing of the sentence.

7. Conclusion

Let me sum up the main points of my attempts to elicit intuitions for an equilibrated theory of cognition and language processing.

The mental operations described by Silvio Ceccato can be considered as elemental synthetic operations, i.e. Micro-operations. The synthetic operations described by Kant can be understood as main or complex mental operations, i.e. Macro-operations.

I have suggested that the micro- and the macro-approach could be associated into a unified whole. The basis of this integration lies in the fact that the micro- and the macro-operations are both operations of object-synthesis. This has been developed first with a system model of Kant's architecture of the mind and secondly with a binary-tree approach to Ceccato's model of thought and language based on the concept of the 'triad'.

Unfortunately, operations of object-synthesis have been hitherto neglected in AI research, which has univocally concentrated on the study of mind as a system manipulating symbols. But this is actually hardly surprising. In fact, the importance given to symbol manipulation is only one component of a widespread tendency based on the natural and inevitable illusion that objects-for-us are ready-made outside of us.

A consequence of this illusion is that too much attention is paid to the receptive aspects of mind, as for instance analysis, whereas productive aspects, as synthesis and autopoiesis, are being neglected. I have shown in some examples that synthesis is altogether of immense importance, and suggested that an equilibrated model of cognitive processing in which analytic and synthetic operations are balanced could improve the frameworks currently used for developing knowledge and language processing in the computer.

A syntactic parser which already partially implements these ideas has been reproposed to the attention of AI research: it shows that this way is viable and could be further pursued.

Acknowledgments

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