# *CYBERNETICS APPLIED TO KANT'S ARCHITECTURE OF MIND*

## *A System Model and its Implications for Knowledge Representation in the Brain and in the Computer*

Marco C. Bettoni, Institute for Methods and Structures, Basel

> Dogmatism ist also das dogmatische Verfahren der reinen Vernunft ohne vorangehende Kritik ihres eigenen Vermögens
> Immanuel Kant

### *Introduction*

Although my education and experience have been mainly in mechanical engineering, my main research interest lies in the field of *abstract concepts* and of the cognitive processing by which our mind operates in order to produce and to use them.

The faculty of operating with abstract concepts is of such an importance for human life that both science and technology are trying to obtain such a processing from a machine.

One way to obtain from machines the same results as human beings obtain them from the mind is to realize in the machines the mechanisms of the mind.

But which mechanisms are at work in the mind when it operates with abstract concepts and how can we study them?

A crucial contribution to this investigation of mental activities can come from a *functional* approach which begins by studying mental functions *independently* of their (unknown) neurophysical basis. The results of such a study can be used

1– for developing an implementation of the functions into an artificial system (computer)
2– for the analysis of their exisiting implementation in the brain.

**Akten des Siebenten Internationalen Kant–Kongresses**. Kurfürstliches Schloß zu Mainz, 1990, hrsg. von G. Funke, Bonn: Bouvier, 1991.

Bettoni, M. (1991) "Cybernetics Applied to Kant's Architecture of Mind". In: G. Funke, Akten des 7. Internationalen Kant-Kongress, Band II.2, 723-741, Bonn: Bouvier.

*1. Neuropsychology, Machine Design, Computer Science and Cognition: The Functional Structure*

By proposing a "re–examination of the concept of function" in neuroscience, Aleksandr R. Luria, the famous neuropsychologist, even claimed [Luria–1976, 1980], that the study of the cerebral basis of any mental process *must be preceded* by a detailed analysis of what he called the "*functional structure*" of that mental process. By "functional structure" he intended a model describing mental main– and partial–functions and their intertwined relations, *independently* of the (unknown) physical functions which support them.

It is interesting to notice that the same concept of "functional structure" is also the basis of modern *machine design* theory. One of the leading theorists, V. Hubka, claims that the design of any artificial system must be preceded by the development of a "functional structure", which describes the future machine *independently* of the (unknown) machine elements which will constitute it. He states, that the anatomical (hardware) structure of a machine can be established by discoursive means only if the functional structure has been *previously* established [Hubka– 1982].

Finally, in computer science we find the same concept of functional structure under the name "Operation principle" [Giloi–1981]. The operation principle determines the functional dynamics of the system and is composed by an "Information structure" (set of operations and of their operands) and by a "Control structure" (flow of the operations): both have to be described in an "abstract" form, that is *independently* from implementation details in a physical structure [Giloi–1981].

Following these views in the case of cognition as a higher cortical function, I decided to develope a "functional structure" of our cognitive system particularly oriented to the processing of abstract concepts.

*2. The Critique of Pure Reason: An Architecture of Mind?*

The idea to use the Kantian text *Critique of Pure Reason* [Kant–1,2] for my purposes came to me when I associated "functional structure" with "architecture" and "abstract concepts" with "pure concepts of reason".

In the *Critique* Kant has a chapter entitled "The architectonic of pure reason" which begins with the sentence "By an architectonic I understand the art of constructing systems" [B 860]

and where he developes his idea of an architecture view on pure reason.

Also I found that in a letter of 1776 to Markus Herz [Kant–3], Kant already underlined the importance of an architecture view and so I concluded that he must have been concerned with such a view from the very beginning of his investigations for the *Critique.*

From this moment I decided to try to read the Kantian text as if it were a description of the architecture of the mind and to *use* it as a basis for the development of a functional structure of the human cognitive system.

*3. Methodological Aspects: The Method of Substitution*

Although Kant is considered to be a philosopher and the *Critique of Pure Reason* a philosophical work, I do not intend to make a philosophical use of his text and to add another philosophical interpretation to the thousands already existing. My use of the Kantian text is a technical one, on the basis of cybernetics.

By technical use I mean my looking for *mechanisms,* for the *dynamics* of the functional structure of the mind system. My aim is to construct, with the help of the Kantian text, a model of those *mental mechanisms* whose activities produce *pure mental constructs.*

To this aim I have also developed the following technique, called the "Method of substitution". This method is analogous to that used in mathematics for the calculation of integrals and I have tried by it to overcome the two main problems of text processing, namely a) the ontology of meaning and b) the text–reader dualism [Meutsch–1986].

The method is based both on my CSI–Model of human communication [Bettoni–1988], which developes the concept of *virtual* communication between operationally closed systems (CSI Closed Systems Interchange), and on Schmidt's approach to text comprehension within the frame of his Empirical Science of Literature [Schmidt–1987].

*Method of substitution* in text processing (MSTP):

1– Choose a frame, a point of view (here: cybernetics) and obtain from it terms, concepts, structures (a priori).

2– Substitute in a few sentences of the original text (here: the *Critique of Pure Reason*) some original terms by using the terms, concepts and structures developed in step 1.

3– Evaluate the redesigned sentences with the criteria of viability and inner coherence. Repeat step 1 and 2 until the substitutions satisfy these criteria.
4– Check by repeating the same substitutions wherever the text contains the same original terms previously substituted and repeat the evaluation of step 3.

As a result, I do not claim to find what Kant "really wanted to say" but simply *to use* his text as a technician and in a coherent and *viable* way.

### *4. The Cybernetic Approach*

My approach to the Kantian text is 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 at the mind as an Information Processing System [Bettoni–1985] and at cognition as a subsystem of mind.
3– For the task of system identification of the mind system I apply a procedure from System 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 over all 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 development principles of the mind.
8– In my architecture view on cognition I constitute and distinguish:

OPERATORS = functional units or subunits, that is 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 compose architecture and process view in a whole to obtain a description of mechanisms, a system dynamic of mind.

We need to study these *mechanisms*, otherwise our cognitive procedures, our science, will remain *dogmatic* [B XXXV].

### *5. A System Model*

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 research is merely at its very beginning.

My system model is *qualitative* and not quantitative (mathematical) because before calculating something, we need to produce, to generate this "something": this can be done only qualitatively.

The text used is a limited but fundamental part of the *Critique of Pure Reason* [Kant–1,2], particularly:

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|---|---|
| – Transcendental Aesthetic | B 33 to B 73 |
| – Transcendental Analytic | |
| Introduction | B 74 to B 88 |
| Analytic of Concepts | B 90 to B 169 |

Note: Because translations of the Kantian terms are misleading, I have decided to use the original german words.

### *5.1 Broad architecture of the mind (Fig. 1)*

The following broad architecture is based on the relation "part–whole" used as a criterium.

There are 2 independent "wholes": the "MANNIGFALTIGE der ERSCHEINUNGEN" (MFE) and the "GEMÜT" (GM): they are represented in Figure 1 by the bar MFE and by the box GM.

The MFE collects all the sources of disturbances which can affect a person.

Unit GM is a main functional unit (operator) collecting those partial functional units by which a person can operate mentally.

I have constituted the partial units of GM by assigning a box to what Kant calls "VERMÖGEN" (faculty) and by assigning relations of "part–whole" as well as connections (channels), depending on my use of different sentences in the text.

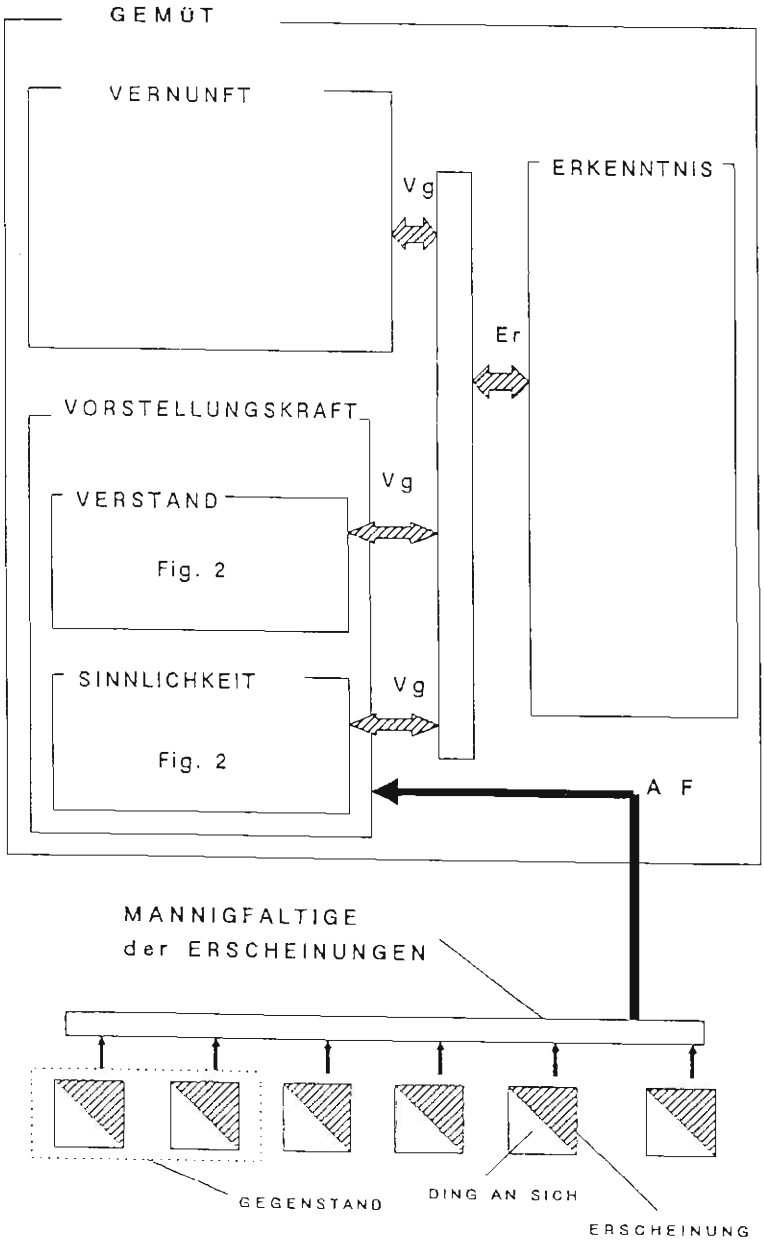


Figure 1 – Architecture of the mind

TABLE 1 : SUBSTITUTIONS DEVELOPED FOR THE ARCHITECTURE IN FIG. 1

| Nr. | KANT's term | Symb. | Cybern. classif. | SUBSTITUTIONS and original text pagings [A..., B...] |
|---|---|---|---|---|
| 1 | GEMÜT | GM | OPERATOR | Functional unit collecting all the functions involved in cognitive processing. [B 74, 75] |
| 2 | VERNUNFT | VF | OPERATOR | Functional unit generating principles. [B 24, 356] |
| 3 | VORSTELLUNG | Vg | OPERAND | Mental construct [B 33ff, 74ff, 92ff, 376] |
| 4 | VORSTELLUNGSKRAFT | VK | OPERATOR | Functional unit collecting the functions of generating mental constructs. [B 34, 51, 130] |
| 5 | ERKENNTNIS | ER | WHOLE | System of integrated mental constructs. [A 97] |
| | | | OPERATOR | Functional unit integrating mental constructs into equilibrated cognitive structures. [B 1, 75, 76] |
| 6 | ERKENNTNIS | Er | OPERAND | Integrated mental construct. |
| 7 | VERSTAND | VD | OPERATOR | Functional unit collecting the functions of generating autonomously mental constructs, without depending on external disturbances. [B 75, 129, 134, 135] |
| 8 | SINNLICHKEIT | SI | OPERATOR | Functional unit collecting —among others— also the function of generating mental constructs depending on external dis- |

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| | | | | turbances. [B 33, 61, 65, 75] |
| 9 | AFFEKTION | Af | OPERAND | Disturbance or perturbation affecting unit SI. [B 93, 309] |
| | | AF | OPERATION | The first steps of an operational sequence by which the unit SI interacts with MFE—disturbances. [B 93] |
| 10 | MANNIGFALTIGE der ERSCHEINUNGEN | MFE | WHOLE | All possible sources of disturbances considered as a whole, as a unit. [B 34, 236] |
| 11 | GEGENSTAND | GGS | WHOLE | An individual, limited source of disturbances collecting ERSCHEINUNG and DING AN SICH. [B XVII, XX, 33] |
| 12 | ERSCHEINUNG | ERS | PART | Part of an individual source of disturbances, which can disturb us and so become involved in the operational sequence in our mind leading to an integrated mental construct. [B XXVI ff] |
| 13 | DING AN SICH | DAS | PART | Part of an individual source of disturbances from which we cannot be disturbed. [B XXVI ff] |

*5.2 Architecture of SINNLICHKEIT and VERSTAND (Fig. 2)*

This model is based on the previous one and it outlines a first refinement of that broad architecture.

It presents some details of the two operators SINNLICHKEIT and VERSTAND, which are the sources of "VORSTELLUNGEN" [B 74], that is 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", "KRAFT" or similar and by

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assigning a module to what is involved in specific operations, what Kant calls "HANDLUNG" (see Fig. 2).

There are two kinds of modules, a static one and a dynamic one. The static one is represented as a sequence of rectangular cells (circular buffer) and the dynamic one 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), 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.

The arrows and bars system, which connects with each other and with the 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 (see 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.

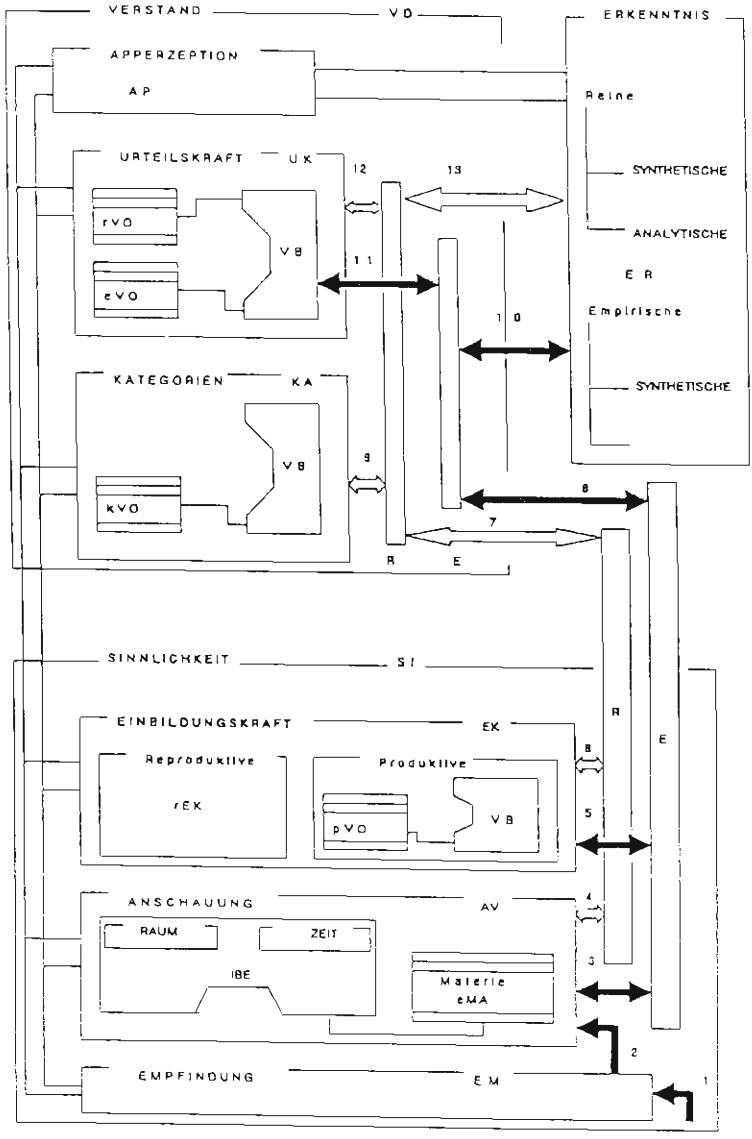


Figure 2 – Architecture of SINNLICHKEIT and VERSTAND

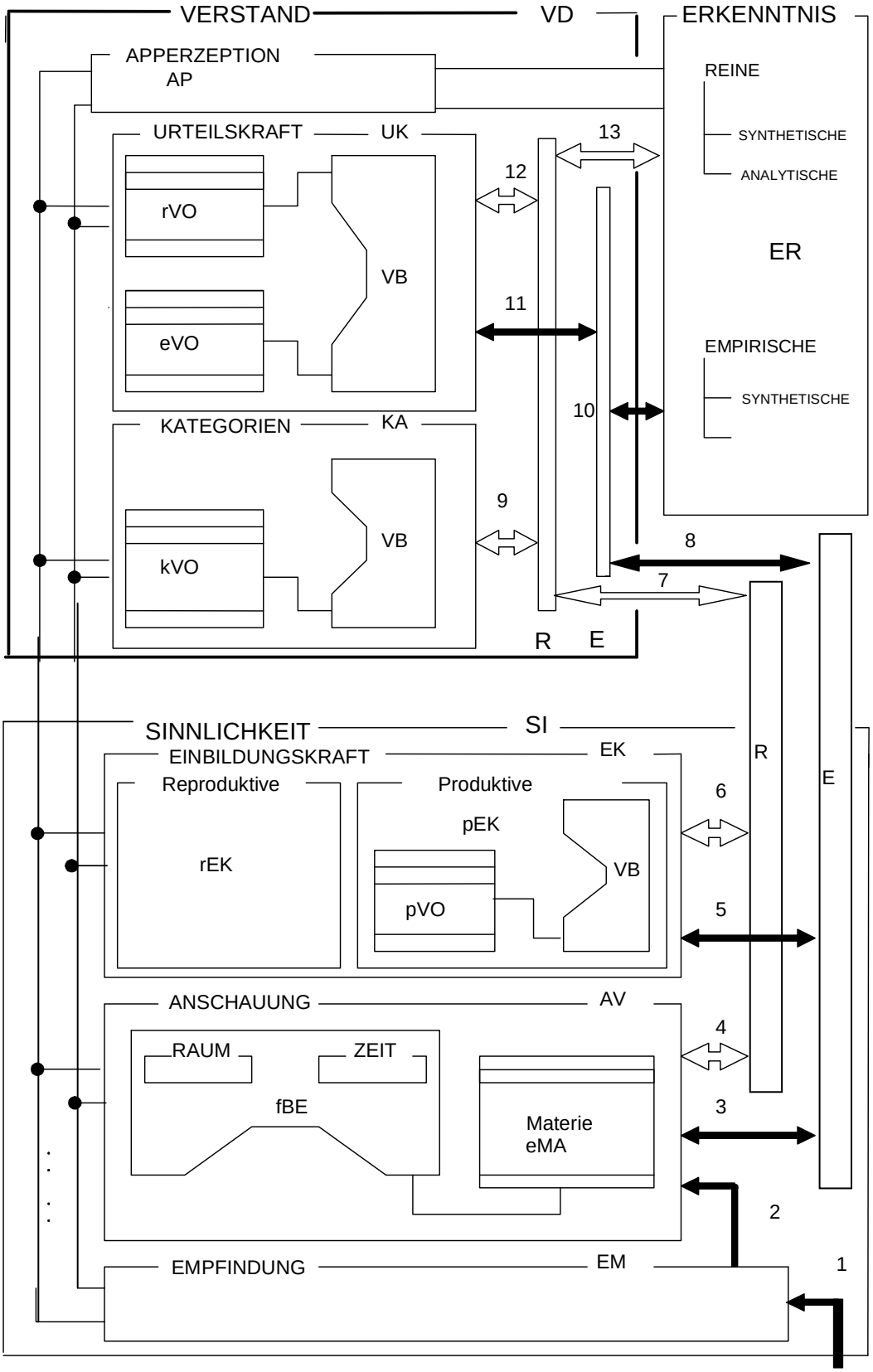


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TABLE 2: SUBSTITUTIONS DEVELOPED FOR THE ARCHITECTURE IN FIG. 2

| Nr. | KANT's term | Symb. | Cybern. classif. | SUBSTITUTIONS and original text pagings [A..., B...] |
|---|---|---|---|---|
| I | Bus, arrows, boxes | | | |
| 1 | ERKENNTNIS-VERMÖGEN | EV | OPERATOR | See Table 1 |
| 2 | REINE ERKENNTNIS | rEr | OPERAND | Autonomously generated and integrated mental construct, independently from external disturbances [B XVI, XVII, 2, 3, 33]. |
| 3 | EMPIRISCHE ERKENNTNIS | eEr | OPERAND | Integrated mental construct generated by functional units among which some depend on external disturbances [B 1, 2, 3, 33]. |
| 4 | ERFAHRUNG | Ef | OPERATIONAL SEQUENCE | Sequence of operations (one of which depends on external disturbances) ending with (result) an integr. mental construct [B 1, 147, 196, 218]. |
| 5 | REINE SYNTHETISCHE ERKENNTNIS | rsE | OPERAND | Integrated mental construct generated by an operational sequence containing assembling operations and independently from external disturbances [B 18, 102, 130]. |
| 6 | REINE ANALYTISCHE ERKENNTNIS | raE | OPERAND | Integrated mental construct generated by an operational sequence |

| | | | | |
|---|---|---|---|---|
| | | | | containing dis—assembling operations and independently from external disturbances [B 18, 102, 130]. |
| 7 | EMPIRISCHE SYNTHETISCHE ERKENNTNIS | esE | OPERAND | Integr. mental construct generated by an operational sequence containing assembling operations and operations which depend on external disturbances [B 11, 196]. |
| 8 | VERSTAND | VD | OPERATOR | See Table I |
| 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 | Functl. unit assembling pure and empirical mental constructs through the activation (application) of operations [B 93, 102, 104 ff, 171]. |
| 12 | KATEGORIEN | KA | OPERATOR | Functl. unit assembling pure mental constructs obtained from the fBE-module and the pEK—unit [B 102 ff]. |
| 13 | SINNLICHKEIT | SI | OPERATOR | See Table I |
| 14 | produktive EINBILDUNGSKRAFT | pEK | OPERATOR | Functl. unit autonomously assembling (by figurative operations) mental constructs from the AV—unit [B 150 ff, 204 ff]. |

| | | | | |
|---|---|---|---|---|
| 15 | reproduktive EINBILDUNGSKRAFT | rEK | OPERATOR | Functl. unit generating the connection of mental constructs form the AV—unit depending on external disturbances [B 150 ff, 204 ff]. |
| 16 | ANSCHAUUNGSVERMÖGEN | AV | OPERATOR | Functl. unit modulating through space— and time—operations what comes from the EM—unit [B XVII, 33, 34, 67]. |
| 17 | REINE ANSCHAUUNG | rAn | OPERAND | Mental construct autonomously obtained by pure operations, independently from external disturbances [B 34 ff]. |
| 18 | EMPIRISCHE ANSCHAUUNG | eAn | OPERAND | Mental construct obtained through pure operations performed on operands from the EM—unit (= perturbations) [B 33, 34]. |
| 19 | EMPFINDUNG | EM | OPERATOR | Functl. unit converting disturbances into perturbations [B 33, 34]. |
| 20 | EMPFINDUNG | Em | OPERAND | Result of the activity of the unit EM = perturbation [B 33, 34]. |

I I Modules

| | | | | |
|---|---|---|---|---|
| 1 | VERBINDUNG | VB | OPERATOR | Component of different functional units collecting the operations of assembling (composing, binding, connecting) [B 102 ff]. |
| 2 | VORSTELLUNGEN | *VO | OPERANDS | Comp. of diff. functl. units collecting operators to be sequentially processed in a VB— |

| | | | | |
|---|---|---|---|---|
| | | | | module (r=pure, e= empirical) [B 33 ff]. |
| 3 | BEGRIFF | BG | OPERA-TION | Assembling operation by a module [B 90, 92 ff, 102 ff] |
| | | Bg | OPERAND | The same assembling operation, considered as a result, as a pattern. |
| 4 | formale BEDINGUNG | fBE | OPERATOR | Comp. collecting the space– and time–operations for the conditioning of perturbations [B 37ff]. |
| 5 | MATERIE | eMA | OPERANDS | Comp. collecting the operators (perturbations) to be sequentially processed in the fBE–module [B 33 ff]. |

## *6. 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.

### *6.1 Example 1*

The *Critique* begins with the sentence (Introduction, B 1):

> Daß alle unsere Erkenntnis mit der Erfahrung anfange, daran ist gar kein Zweifel;...

and continues a few lines later:

> Wenn aber gleich alle unsere Erkenntnis mit der Erfahrung anhebt, so entspringt sie darum doch nicht eben alle aus der Erfahrung.

This text can be mapped into the system model in the following way (use the two tables 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 whole operational sequence is all composed by that kind of operations.

### *6.2. 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:

> .....Das erste, was zum Behuf der Erkenntnis aller Gegenstände a priori gegeben sein muß, ist das Mannigfaltige der reinen Anschauung; die Synthesis dieses Mannigfaltigen durch die Einbildungskraft ist das zweite,...Die Begriffe, welche dieser reinen Synthesis Einheit geben, und lediglich in der Vorstellung dieser notwendigen synthetischen Einheit bestehen, tun das dritte zum Erkenntnisse eines vorkommenden Gegenstandes,...

In my system model I describe this as follows:

– to obtain a pure integrated mental construct we need as first the operations of the module fBE (which condition the perturbations) alone, without operands from the unit eMA;

– as next we need the operations of assembling performed in the unit pEK on the results of the first step which are collected in the module pVO of the unit pEK;

– finally, the third step is performed on the pure assembly obtained from step 2, by operations which assemble it to obtain a new unity related to the object involved in the process.

## *7. Concluding Remarks*

"Knowledge Representation is perhaps the most central problem confronting artificial intelligence". This sentence introduces a recent collection of "Essays in the Representation of Knowledge" [Cercone and McLalla–1987], which shows that nearly all central domains of AI are experimenting with knowledge–based systems.

Unfortunately, all eight maior approaches to knowledge representation (logical representations, semantic networks, procedural representations, logic programming formalisms, frame–based representations, production system architectures and knowledge representation languages), have a common disadvantage, which prevents them from obtaining better results: they are *dogmatic* in the Kantian sense [B XXXV].

This *dogmatism of Artificial Intelligence* consists in the presumption, that it is possible to make progress with Knowledge Representation, according to principles and by using pure concepts in the same way as reason has long been in the habit of doing, *without* having first investigated in what way, by which mechanisms and operations, the "faculties" of our mind process *pure* mental constructs to obtain those principles and concepts.

The aim of my paper is to show, that a necessary preparation for a thoroughly grounded Knowledge Representation research is an investigation (a *Critique*) of our *pure* mental mechanisms. I have suggested that a possible approach is to develope a "functional structure" of our cognitive system and that a preparation to this development could be obtained by reading from a cybernetic point of view Kant's *Critique of Pure Reason.*

The system model presented here suggests to look at knowledge as a dynamic structure, that is a structure made of operations, (see also Sala–1971) and that these *operations are what "represents" knowledge* in our brain.

This approach is in line with Winograd's "use of procedures to represent meanings" [Winograd–1972], but is more radical and I think that in spite of the "complexity barrier" [Winograd–1972] it should be possible to further develop the faculties of SHRDLU in understanding English, by combining Winograd's procedural system with my operational system.

If the operations of a functional structure are what represents knowledge in our brain, then it should be easy to obtain a representation of knowledge in the computer by transferring the functional structure of our mind from its natural implementation in our brain to an artificial implementation in a computer. I think that especially data flow computers could provide a convenient architecture for this kind of application [Giloi–1981, Hwang and Briggs –1985].

My system model is only a rough sketch, but I am sure that it is possible to obtain a refined system by a huge comprehensive investigation exploiting from a cybernetic point of view

what Kant has written in the *Critique of Pure Reason* and in other works about mental mechanisms.

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