COGNITIVE PROCESSES - REPRESENTATION OF EVENTS AND OPERATIONS FROM THE VIEWPOINT OF DENDRITIC COMPUTATION

J. Simões da Fonseca[1], J. Barahona da Fonseca[2] and I. Barahona da Fonseca[3]

[1]FACULTY OF MEDICINE OF LISBON,
Fax: 351-1-796 40 59
AV PROF EGAS MONIZ, 1600 LISBOA, PORTUGAL.

[2]FCT/UNL, DEPARTMENT OF ELECTRICAL ENGINEERING
Fax: 351-1-2957786,
E-MAIL:AO@FCT.UNL.PT,
QUINTA DA TORRE, 2825 MONTE DA CAPARICA, PORTUGAL

[3]FACULTY OF PSYCHOLOGY OF LISBON,
Fax: 351-1-793 34 08
ALAMEDA DA UNIVERSIDADE, 1600 LISBOA, PORTUGAL.

Abstract: Using an approach based in recent advances in the knowledge of dendro-dendritic synaptic processes and transmission of spikeless graduate signals we analyzed some issues concerning symbolic processing of visual and auditory information

A similar viewpoint was used to deal with cognitive structures of knowledge. Problem solving and intentional behavior are examined in the context of the logic of frames and script models, implemented by dendro-dendritic computation in the brain.

Introduction

The motivation for this work was raised by a set of experimental results which led to the establishment of significant relationships between cognitive and affective states and patterns of periodic waveforms detected and identified in the electroencephalogram, using cross correlation methods (1,2).

This method eliminated the need of an external time mark reference (for instance stimulus initiation) from which result some limitations associated to the use of evoked potentials as indicators of brain functions related to psychic events.

Lee Method for the detection of periodic waveforms, was applied for signal identification in EEG recordings (13). We used cross correlation with dirac function periodically repeated with frequency equal to that of the component to be identified.

Dendritic Computation

In dendrodendritic trees signals are significantly distinct from action potentials as they do not depend on threshold non linear generative rules which determine the all or none characteristics of these later signals - both concerning duration and amplitude.

Dendritic potentials are graduate potentials with amplitude close to that of action potentials which propagate with small decrement when they progress from more proximal to more distal sites (relatively to the cell body), along dendritic trees (8).

They have a much more variable waveform, duration and amplitude than action potentials. These characteristics of dendritic potentials which express on a graduate form the dimensions of excitatory and inhibitory processes that generate them, render dendritic potentials possible candidates for a putative code for the representation of events in which they will play the role of information carrying signals.

The variety of temporo-spatial configurations which may be assumed by ensembles of such signals circulating in dendrodendritic trees makes them possible candidates for an encoded representation of cognitive processes in terms of neurophysiologycal correlates.

Methods of direct observation are not available, concerning these hypothesis, we may use an approach based on the proposal of theoretical models for formal dendritic networks and computation.

Concerning the calculations involved in the computation of sub functions as convolution and cross correlation in which it is necessary to model nonlinear multiplicative and divisive interaction, some examples have been developed (3,5).

We will consider another aspect which concerns the capability of these dendritic circuits to perform logical operations.

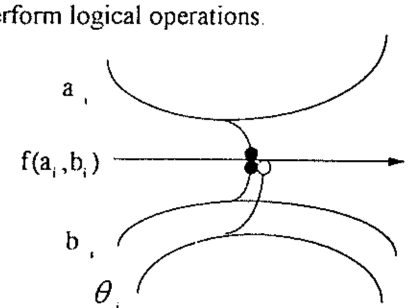

Figure 1 - This dendro-dendritic network implements intersection or else union between elements of two arrays A, B according with threshold θ_i. The threshold vector carries the conditions which define the logical operations which are performed by these dendro-dendritic networks.

Functions such as component to component union or else intersection between vectors of the same dimension can be represented by very elementary circuits which function as coincidence filters involving circulating arrays of signals which represent the components of each one of the two vectors respectively, and a third array of components which specifies thresholds for each interaction between elements.

This structure which relates graduate potentials interacting over a fourth dendritic network specifying thresholds dimensions implements in a dynamic form structures which are usually attributed to synaptic weights and fixed thresholds.

What should be noted in this example is that threshold logics which usually is implemented under the form result of a fixed structure of synaptic weights and interactions and a specified set of fixed values for threshold and characterization of possible range of variations is here represented by a dynamic process of computation which depends, for its efficiency, on adequate encoding and generative processes for all the signals that specify the symbolic representation for any logical function.

The interaction rules produce different elementary functions which do not require a distinct operational structure for each case.

This specification will be performed by some dendritic structure depending only on a_i, b_i and θ_i .

These functions can be dynamically modified through simple modification of signals a_i, b_i and threshold θ_i providing a model for learning which conventionally would depend on synaptic excitation and inhibition and here would correspond to the generation of distinct values for the components a_i, b_i and θ_i in their characteristic sequences.

The problem of transposing data acquired through associative learning to the domain of higher level symbols would here be translated to a much more general procedure of recoding sequences with the possible direct contribution of perceptual , motivational and attentional and other types of psychophysiologycal processes.

As we did extensively discussed in preceding works, dendritic processes and signals may provide the machinery for symbolic processes in which the meaning of any message, at an elementary level, will rest on referential analogy. At higher level of the hierarchy of the representation through signals , the meaning attributed to signals which makes them significant symbolic entities will be defined through information processing chain implemented by neurphysiological processes which successively operate in sequential or parallel computational modes which lead simultaneously to neurophysiologycal signal as well to the symbolic level which is carried by this signal.

An open possibility is that much of these information is not dynamic and physiological but rather structurally and anatomically determined by operators that Central Nervous System has available to process information.

In this case the core of information processing will be placed on structure which is a mode of organization complementary to the dynamic structure we presented before.

In the same works we also analyze the possibility of constructing complex symbolic processes related to the identification, for example, of a human face or a musical theme, using dendritic computation - these are paradigms for a possible mode of representation of information at a cognitive level. Note that although these processes are symbolic, they are encoded in visual and auditory computational languages and not within the linguistic system of verbal representation in human communication.

Plans of action and the internal space of representation.

Sensory motor squemes observed during the first period of cognitive development which lasts until the use of linguistic system of communication provide evidence enough to support the concept of an inferential system based on visual, acoustic and other sensory modalities data. Children use this system to integrate sensory experiences with motor schemes which are clearly intentional, as can be observed, for instance in repetition games as well as in symbolic games which precede the acquisition of linguistic competence (18,19).

The use of intentionally organized schemes proves the existence of cognitive operations which direct action to the attainment of a goal through complex hierarquically organized sequences of acts.

We can use those sensory processes as a paradigm for cognitive operations organized over a symbolic system of representation directly linked to sensory information processing.

We did show in previous works how signals intervening in dendritic computation may be invoked as a physiological support of meaning in symbolic computation.

Sensory motor organizations show that intentionality can also be attributed to these processes.

As it was proposed by J. Simões da Fonseca e J. Mira y Mira (22), the signification and intention processes may be defined through the set of decision rules which led to the construction of an internal representation of interaction with the environment as well as to outputs which command motor effectors.

These concepts were developed within the context of a generalized theory for formal neurons.

We may invoke here neurophysiologycal data obtained by Sokolov (23) concerning the processes involved in the formation of a neuronal model of the environment and, in the learning theoretical and cognitive approaches, the sign-gestalt-expectancy proposed by Tolman (24, 25) which involves the use of an internal space of representation in problem solving and in the process of planning and performing adaptive strategies to deal with variable characteristics of the environment.

In our dendrodendritic formulation this corresponds to the concept of an organized subset of dendrodendritic computational compartments which receive, process, not only sensory information, but also motivational and emotional information as well as data recorded in memory which allow the prediction of the outcome of actions and the planning of strategies linked to the attainment of significant goals.

The more likely paradigm which allows the integration of all these data and computations is the concept of script grammar.

We admit that a script implies initial conditions and a succession of stages in the performance of the script which directs the action of the subject as well as the action of the environment toward the subject.

The transition from one stage to the next will depend on the fulfillment of satisfaction criteria. To overcome the difficulties posed by circumstances which prevent the fulfillment of purpose on one stage due to environmental characteristics, then an inferential procedure will specify hypothetical conditions which would be adequate to produce the attainment of satisfaction criteria through their interaction with the decision rules which direct the action of components linked to the subject's behavior and the reaction of the environmental agents.

We conceive these processes as double control processes at a single level of computation which is furthermore complemented by a second loop of control which leads to the production of new data that may contribute either directly or else through inferential processes, to the specification of characteristics which were latent in the description of the interaction and which were rendered ostensive through this inferential process.

This approach may be implemented at the logical level through a calculus of signification and intention involving the definition of matricial operators which act on state functions transforming them.

The script paradigm

In script theory the representation of intentional interaction with environment using symbolic representation may be conceived as a process which involves the decision rules characteristic for the agent as well as rules which generate those reactions which may be attributed to the environment, involving agents or in general any generative process which produces sequences of reactive states (21).

In this approach the subject is supposed to have available a set of rules to act on the environment, they aim to modify the environment and, on the other hand there is a specified range for the modifications that may be imposed on them through the interaction with the environment. The same applies to the generative rules which are attributed to the environment considered as a complementary system which also intervenes on cooperative , or else conflitual way with the actions produced by other agent. That is, the environment is supposed to act using a set of decision rules which are formally similar, in some aspects, to that used by the subject.

The state variables of both systems allow the definition of successive states included in processing stages with associated satisfaction criteria, as well as criteria for the failure of the goals attainment due to reactions of the environment, $f_{i,n}$ and $g_{i,n}$ respectively.

In each stage of the interaction the subject performs a walk along a space of states S_k, S_l...etc. To each one of these states correspond a state function

$$p_{i,j}\,(u_m, v_n)$$

In which **u** stands for variables of the environment characteristic for the specification of the subject action, and **v** for the environment's reactions, $p_{i,j}$ represents the decision rules used by the subject which are characteristic for each state.

On the other hand the conjugate function

$$q_{a,b}\,(u_c, v_d)$$

q specifies the decision rules which characterize each state reaction of the environment which occurs simultaneously with the use of the corresponding p function.

The process of generation of successive states S_i is specified by application of rules p and q respectively over variables u and v.

This process may be conceived as a trajectory in which the subject after having generate a state function

$$p_{m,n}\,(u_i, v_j)$$

which is associated to the reactive process characterized by

$$q_{v,b}\,(u_e, v_f)$$

undergoes a transition to the immediately successive state function

$$p_{m,\,n+1}$$

through the transformation

$$Tp_{m,n} = p_{m,n+1} \quad R.\ q_{c,d} = q_{c,\,d+1}$$

and similarly, in the case of the environment in which **T** and **R** represent the transformation rules characteristic of state functions **p** and **q** respectively.

There will be a function characteristic for the final state which is wanted by the subject

$$f_{i,n}(u_k, v_j)$$

as well as reactive functions which fulfill the intentional structure of the environment - which are incompatible.

$$g_{r,s}(u_o, v_p)$$

If criteria $f_{i,n}$ is satisfied the subject concludes a stage and initiates a new stage of interaction.

The whole process is characterized by a concurrent computation involving state functions **p** and **q** functions and their characteristic transformations T and **R** together with final criteria f and g respectively.

This concurrent computation may be thought as a special case of mutual control involving not only the attainment of final criteria, but also a characteristic set of trajectories allowed or forbidden respectively, according with the intention which will prevail in the case of conflitual concurrent processes.

In case of criteria $f_{i,n}$ is not attained and on the contrary g_i is satisfied, then transformation operators T and R will be changed in order to allow the essay of new decision rules expressed by state functions p' and q'.

Finally, in the case of repeated failure, an inferential procedure **H** will produce a set of hypothesis $\{h_1, h_2, ..., h_n\}$.

To each of these hypothesis h_i correspond principles with new decision rules that will lead to new state functions p'' and q'' may be obtained deductively. These new decision rules will be introduced in the process and a cycle of operation will be reinitiated in the same stage aiming the attainment of f and avoidance of g.

Final Remarks.

Our aim was to show that setting apart the use of linguistic computation, symbolic systems of script logics, logic of frames and predicate calculus can be implemented within the context of dendrodendritic computations.

This way detailed models concerning neurophysiologycal processes involved in cognitive operation can be developed and possibly extended to the domain of linguistic competence producing a set of hypothesis which will contribute with a functional concept that complements more conventional localizational views.

In our approach we were deeply influenced by the teaching of Warren McCulloch which has exerted a deep influence in the orientation of our study.

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