A Non-Linear Stochastic Model for Higher Nervous Activity Based on Experimental Data: Principia Mathematica Psychologiae Naturalis II

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Abstract
In this work we consider phenomena or multisensory convergence as leading to a process of representation which possesses a higher degree of abstraction than it would result from a representation by multiple specific sensory processes considered as a heterogeneous ensemble. It can be immediately noticed some analogy with other systems of the brain, namely with reticular ascending activating system which is formed by networks of cells and their connections, each one responding to multiple sensory heterogeneous efferents. Nevertheless there are some remarkable differences between the two types of multisensory convergence namely the level of representation of associative multisensory systems is more elaborate, more precise and implies a higher level of differentiated abstraction than it is the case with cells of the reticular system witch serve only functions of arousal of the brain or control of the sleep-wakefulness system or attention. We show that the processing of EEG and ERPs signals by the Lee detection method and then by Fourier analysis can be used to identify high abstraction level cognitive processes and emotional states. Finally we present some examples of application of Lee method to ERP and EEG records.
Keywords: Neural Basis of Cognitive Processes, Identification of Cognitive Processes, Lee Detection Method, Periodic Band Pass Filter, Fourier Analysis.

1. Multisensory Convergence in Simple Neurons of the Cerebral Cortex

Early studies in this subject (Jung, *et al.*, 1963) show the existence of multisensory convergence in simple neurons of the cortex. The modalities that were studied were vision, audition and equilibrium. Probably data concerning somato-sensory information processing were also recorded although not identified. Later data show that stimulation of the stomach by water and variation of the pressure inside that organ through the inflation of a balloon introduced in the stomach, modified significantly visual information processing in the brain. This convergence was not of a single type; there was long latency convergence with a long lasting period, which probably could be attributed to the action of the reticular system. On the other hand, clear-cut neuronal responses with relatively short latency might be attributed to association networks as they came to be clearly identified in subsequent years. Finally, remarkable data appeared concerning the occurrence of multisensory responses in the primary visual or in the primary acoustic cortex. That is, the primary representation of sensory information did not stand the proof of experimental data, because convergence was immediately apparent already in primary visual and in primary acoustic areas.

The main importance of this data concerns the fact that sensory quality, that is, specific sensory quality, was lost in this neurons, because what they effectively produced as a response were trends of spikes, two responses belonging to an equivalence class of responses either to visual-acoustic or labyrinth stimulation.

Messages contained this way possibly mixed information, and this model of functioning must be considered concerning higher nervous activity because, in some sense, this type of functioning implies already some kind of processing similar to abstraction, that is, information or equivalent classes. This allows the possibility or proposing a different model for sensory information processing in the brain cortex, as we shall see later in this paper.

2. Visual Information

In a preceding paper (Fonseca *et al.,* 2009), we proposed a model for vision in which we were able to pass from two to three dimension representations and we were also able go to a tensorial representation of the human body. Finally, we come to identify semantic and logical attributes concerning visual information, now treated as a symbolic representation or reality. In this paper we are revising an interpretation of retinal function, which was only approximate because we did consider Retina as a planar surface belonging within an Euclidian geometry. We can now consider the initial light projection in retina surface and further pre-processing in the eye as implying a curved surface, that makes sense because not only Retina is a curved surface, reality may be represented in circular coordinates, the radius of circular coordinates of representations of reality being approximately coincident in direction both for points in space and their projection in Retina. The convergence of the eyes which is required in vision together with real size or objects as they are projected in Retina produces the effect of perspective and provides those indicators which are required to obtain the make believe effect or perspective in plain surface painting.

We admit now in the processing and in a computation implementation of our ideas, a three-dimensional model of space of scenic, or rather of oval type.

In one preceding work we were able to interpret neuronal responses using the conventional concept of excitation-inhibition addition of excitatory and inhibitory processes in time and space. This corresponds to the usual approach to understanding the neuronal functioning in the perspective of the higher nervous activity that they cannot be more than elementary information processing. This neurons are present everywhere in brain activity, but are integrated as machine language elements on an assembling line program that puts together this information processing units, as well as a complicate network or neuronal information processing devices which we will try to clarify. In a series of experiments made with Inmaculada Garcia Fernandez (1985), including her Ph. D. thesis, we used as stimulus a special sinusoid, inspired by the work of Campbell. Besides spatial vertical, horizontal and crossed sinusoids, we also used white noise stimuli defined as a Poisson distribution of delta waves, with equal probably density of positive and negative delta waves. The components of the stimulus in the frequency domain, showed as a uniform distribution.

Using the relationship

$$Y(w) = H(w)\, X(w) \tag{1}$$

and considering the uniform distribution of the components in the frequency domain of the stimulus, and recording the evoked response and its Fourier transform we can immediately obtain $H(\Omega)$ given our recording of evoked potentials and the calculation of representation in the frequency domain.

This is a non-linear process. Nevertheless, we can use a more appropriate mathematical representation in the version presented by Wiener (1949) with filters whose kernels allowed the possibility of obtaining an independent probability distribution for the variables corresponding to the processes which are involved. So, if we consider what is happening in the brain during the hooked potential, we can represent the information flow in the brain s cortex by means of a coherence function.

Furthermore we have now means to characterize normal and pathological processes in the brain. Namely, in the case of depression, we can compare coherence measures both in normal subject and in subjects suffering from dysthymic disorder, under and not under treatment by an anti-depressive agonist of noradrenalin, Maprotilin. Note that, where we used crossed vertical and horizontal sinusoids, we obtained an approximately flat distribution of the frequency domain components, similar to those obtained with a white noise stimulus. This is probably due to the fact that, in this case, subjects were required to produce motor responses. As a consequence long latency components in the time domain were similar in both cases independently of the two different of stimuli (P300, readiness and motor responses) obviously, local time components are not discernible directly individually because Fourier transform is a global transform; nevertheless we know that a component of slow frequency is much more relevant here than in responses in which subjects don't haven to produce a motor response. Finally, it is clear that this type of response is also present when subjects don't have to move, and probably this means that what the representation of movements is about is the decision making process, which is not so different in the case of giving a motor answer or deciding not to give it; although in some sense it is ambiguous to decide to give a motor response because it requires a preparation of the movement with many co ordinations either at the segmental level, or else at global level of the organism. Earlier, the investigation of Barahona da Fonseca (1985) and Barahona da Fonseca *et al* (1985) concerning free imagination show clearly that it is possible to classify states of emotion - joy, sadness, anger and anxiety and suspicion using as indicators a) the spectral representation of responses in different areas of the brain; b) differences in regional distribution of power spectrum components. In this case it was used to clean up noise and to ameliorate the signal to noise ratio which consists of the use of a comb with delta waves repeated with a frequency *n* and making the cross correlation between this comb and the registered EEG signal. Differently from Fourier transforms, Lee transforms (Lee, 1964) preserve not only the frequency but also the waveform of the wave represented in the brain, in case they exist. Making the Fourier transform of these waves, considering only the amplitudes of the power spectrum for $f=1/p$, $2/p$,.., i / p, p being the period of the detected waveform, allows the synthesis of a power spectrum different from the one that is obtained in the conventional way and allows the use of these frequencies to identify the type of emotion the person is feeling.

As a matter of fact, in many cases the identification of the emotional state was possible with a high degree of precision, what means that those that like Searle say that the semantic content of the brain functioning is not possible to be represented in a machine paradigm are wrong because in frequency we can identify the waves like they are in the brain and producing a multivariate spectral classification we can separate the state of the brain according with the type of emotional fantasy the subject is doing. Wiener's proposal is to consider a decomposition of the operators involved in processors in terms of filters within the framework of stochastic processes with independent variables.

The ergodic principle states that for a stochastic process stationary in time and memory less the main value of infinite measures in a single instant is equal to the main value of infinite measures made in one single system during an infinite of time except for a non null subset that that has measure 0.

That means that it is perfectly acceptable to base our data on simple subject observations provided they are repeated a very high number of times as if they had the same mean value as a high number of distinct values in a single instant.

3. Information Processing in Networks of Neurons in the Brain

Let us consider now a channel in which the information that is sent by the encoder and decoded by the receiver concerns the representation of logical propositions. Suppose that we have a logical relationship between propositions x and y,

$$x + y \Rightarrow xy + \bar{x}\,\bar{y} + \bar{x}y \Leftrightarrow x + y \Rightarrow \bar{x} + y \qquad (2)$$

Let us suppose that symbols x and y considered isolated occur with stationary probability $P(x) = P(y) = p$ and $P(x = 0) = P(y = 0) = 1 - p = q$.

We further consider that signals $x = 1$ and $y = 1$ are corrupted by noise in a way such that the conditional probability of $P(x = 1 / x = 1) = p'$ and $P(x = 0 \setminus x = 1) = q'$, $p' + q' = 1$ and the same holds true for y;
the conditional probability of $P(x = 0 \setminus x = 0) = q''$ and $P(x = 1 \setminus x = 0) = p''$.

We can now calculate both the joint probabilities and the mean entropy for relevant cases: a) isolated symbols p and q for the case of a pair of symbols pq and $\overline{H_1} = - p \log_2 p - q \log_2 q$.

Let us suppose, for the sake of simplicity that p = p' = p'' = 1/2.
We have immediately $\mathbf{H}_1 = 1$.

In the particular case we are considering in what concerns the preservation of information concerning the logical relationship errors that convert mean terms of the normal disjunctive form into other mean terms for which the logical relationship holds true are not considered as corruption of the propositional message.

$$P_1 = P(xy \setminus xy) + P(x\bar{y} \setminus xy) + P(\bar{x}y \setminus xy) = p^2(p^2 + pq + q\,p) \tag{3}$$

$$P_2 = P(x\bar{y} \setminus x\bar{y}) + P(xy \setminus x\bar{y}) + P(\bar{x}y \setminus x\bar{y}) = pq\,(p'q'' + p'p'' + q'q'') \tag{4}$$

$$P_3 = P(\bar{x}y \setminus \bar{x}y) + P(xy \setminus \bar{x}y) + P(x\bar{y} \setminus \bar{x}y) = qp(q''p' + p''p' + p''p') \tag{5}$$

$$<H_1> = P_1 + P_2 + P_3 \tag{6}$$

$$<H_2> = (x + y) = - P_1 \log_2 P_1 - P_2 \log_2 P_2 - P_3 \log_2 P_3 = 2.25 \tag{7}$$

Finally let us consider those cases in which noise corrupts information about the proposition:

$$P(\bar{x}\,\bar{y} \setminus xy) + P(\bar{x}\,\bar{y} \setminus x\,\bar{y}) + P(\bar{x}\,\bar{y} \setminus \bar{x}\,y) = p^2\,q'^2 + pq\,q'\,q'' + qp\,q''\,q' \tag{8}$$

And the amount of information that is corrupted is given by

$$<H_3> = - P_4 \log_2 P_4 = 0.75 \tag{9}$$

As a single mean term is sufficient to make the logical relationship hold true, the amount of redundancy is

$$R_i = (P_1 + P_2 + P_3) - P_i \qquad \text{for } i = 1..3 \tag{10}$$

4. The Multisensory Encoding

We can admit that besides the traditionally considered type of specific sensory encoding there is a kind of multisensory representation in which all information is mixed in a joint process and there are transducers n the periphery, for instance in neurostructure of viscera or other organs of the body which detect the part of the information that concerns themselves. As a matter of fact we admit that the brain "talks" with viscera, viscera talk with the brain and this is made by means of two components, the neuronal component through the sympathetic and parasympathetic systems of the autonomous nervous system and also by means of neuropeptides which set the filters tuned for the information which is relevant to them. In case the tuning is not made adequately, serious disturbances, even structural, may result. An easy way to represent what seams a complicated process is to admit that specific information is encoded by specific frequencies and that wave forms of its specific frequency can be retrieved by cross correlation with a Dirac's comb, formed by delta waves repeated with that frequency *n*, with Δn which allows the identification of the periodic function of frequency n, fn(t), the component of frequency *n* in f(t).

$$Fn(t) = \frac{1}{N}\sum_{i=0}^{N-1}\int_{-\infty}^{\infty}\delta(t - i/n)f(t)dt = \frac{1}{N}\sum_{i=0}^{N-1}f(t-i/n) \qquad (11)$$

The signal to noise gain of this *detection* increases with the frequency *n* since *N* increases with *n*, *N* being given by

$$N = \frac{\Delta t_{buffer}}{T} = n\,\Delta t_{buffer} \qquad (12)$$

where Δt_{buffer} is the EEG sample duration. This detection method can be interpreted as an implementation of a periodic band pass filter with period *n*, gain *N* and each band pass filter having a bandwidth of $2/\Delta t_{buffer}$. This means that if we increase the EEGs/ERPs recording time, Δt_{buffer}, we also would have a narrower periodic band pass filter.

In figure 1 we present the *equivalent transfer function* of Lee method and in figures 2 and 3 the results of application of Lee method to a record of ERP and EEG, respectively.

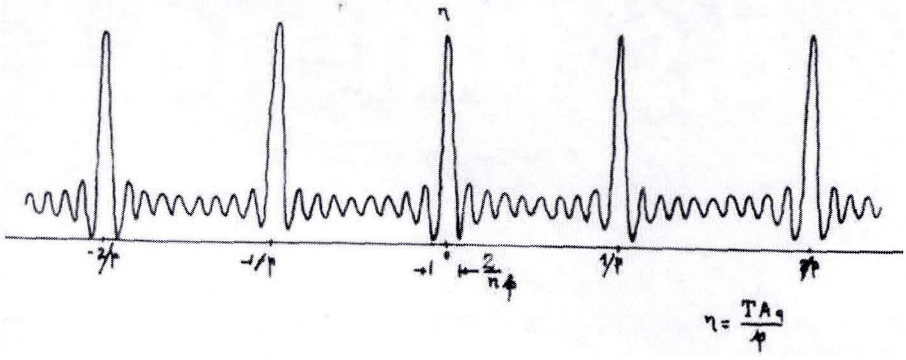

Figure 1: Equivalent transfer function, *H(f)*, of Lee detection method. Variable *p* means $1/n$ and T_{Aq} means Δt_{buffer}. Note that $N\,p = \Delta t_{buffer}$ so the width of each main lobe is $2/\Delta t_{buffer}$ and its height is *N*.

Figure 2: The first wave represents the original visual ERP with Δt_{buffe} =1s recorded with electrodes placed on the scalp in Temporal Anterior and Temporal Posterior areas. The second and third waves are the periodic detected waves of 2Hz and 5Hz, respectively.

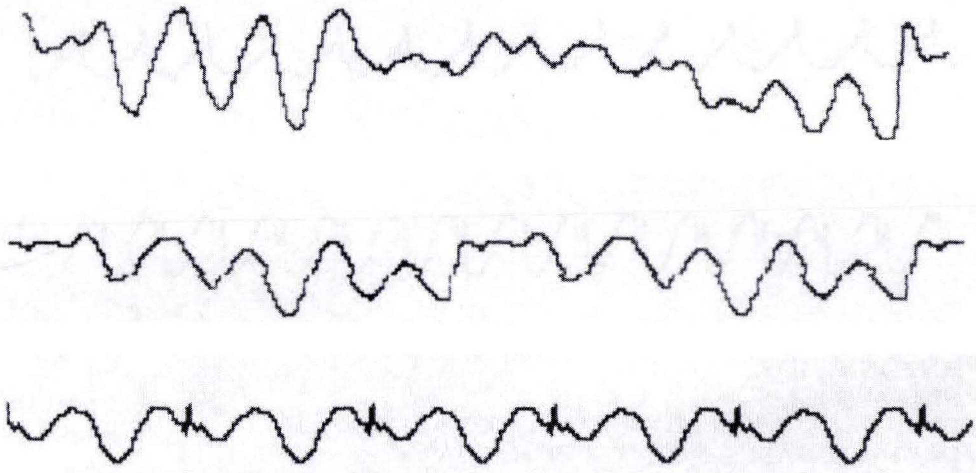

Figure 3: The first wave represents the original EEG without stimulus with Δt_{buffer}=1s recorded with electrodes placed on the scalp in Temporal Anterior and Temporal Posterior areas. The second and third waves are the periodic detected waves of 2Hz and 5Hz, respectively.

For instance, if in the Seligman's paradigm experiments, in which the experimental situation includes a highly painful experience, which the subject cannot avoid in any way he develops a gastric ulcer, when subjects can defend themselves or try to defend themselves the ulcer does not occur anymore. So we can admit that neuropeptide transmitters may act on the stomach and activate the helicobacter pilori and provoke ulcers or even carcinomatose expressions of disease. Also in the case of multiple scleroses very highly traumatic experiences might provoke the activation of enzymes destructing the myelin component of the coverage of neurofibres and so producing extensive loss of neurons or other types of psychopathological disorder.

5. Conclusions

We have considered phenomena or multisensory convergence as leading to a process of representation which possesses a higher degree of abstraction than it would result from a representation by multiple specific sensory processes considered as an heterogeneous ensemble.

It can be immediately noticed some analogy with other systems of the brain, namely with reticular ascending activating system which is formed by networks of cells and their connections, each one responding to multiple sensory heterogeneous efferents.

There are, nevertheless, some remarkable differences between the two types of multisensory convergence namely the level of representation of associative multisensory systems is more elaborate, more precise and implies a higher level of differentiated abstraction than it is the case with cells of the reticular system witch serve only functions of arousal of the brain or control of the sleep-wakefulness system or attention.

The same is true, in terms of our present day knowledge concerning the motivational system and the emotional system although as the cognitive components of motivation and emotion imply, at the final stages of processing a differentiated and refined system of symbolic representation.

While reticular system activates or inhibits extensive areas of the brain, multisensory convergent systems activate in a precisely directed way multiple differentiated areas performing a binding role between them.

As abstraction systems involve the use of conceptual representations and the understanding of complex patterns of symbols which concern either objects of the nature, of the body or of the understanding of the world.

So, at this level we have to consider propositional as well as intuitive thought expressed by the linguistic declarative system as well as by the non linguistic non declarative of symbolic reasoning.

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