Emotional Brain Activation Model Based on Computer Theory and Digital Image Processing

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Abstract — Human beings are constantly stimulated to activate mental operations associated with emotion. Moreover, there are different neural mechanisms that correspond to each emotion degrees. Science lacks knowledge on the operation of such mechanisms, despite being notorious that some regions are related to particular emotions. Modern studies generally enumerate the relationship <*mental process, activation region*>, while it would be much more interesting if they try to explain the brain engine aspects. This article intends to present a technique for modeling human brain as a computable object by using Computer Theory and Digital Image Processing. A pattern cerebral activation recognizer Turing Machine was constructed from functional magnetic resonance images in order to systemize the cerebral activation human process for a limited set of emotional stimulations.

Keywords: emotional brain activation, theorem proving, functional MR images, volumetric images.

I. INTRODUCTION

Emotion is one of the complex functions human brain is capable of producing, and the neural mechanisms associated with each mental operation are different. It is known that there are relationships between some cerebral regions and emotions, but science lacks knowledge about such mechanism. From this point of view, it is not sufficient to merely enumerate the relation <*mental process, activation region*>, as it is currently done. It is necessary to elucidate the aspects related to the mechanical functioning.

This article is a complement to previous studies [1] and aims at improving the understanding of cerebral activation process by an attempt to model human brain as a computable object. Its originality lays on the fact that there are no computational models for mechanical, spatial and temporal brain activation. The available models are associated with chemical and cellular process, such as quantitative finite elements models and neural networks.

Brain mapping is an ambitious goal which is far to be reached. Under the "modern" perspective, there are no individual regions responsible for vision, language, or even reason and social behavior. Actually, there are several systems composed of some interconnected cerebral modules, whose dimension may vary from a neuron to a cytological uniform region. Besides, according to its relative position in the system, each cerebral module contributes to different behavior of brain operation, and for this reason, those modules are not permutable. This is a relevant aspect, since what defines the cerebral function contribution to the system operation is not only the structure itself, but also its spatial location in the system.

Brodmann areas form a cerebral mapping system based on a cytological division, which is widely used as spatial determination of neural activity and as a neurosurgery guide [2]. Furthermore, there is also another mapping technique, more precise, based on a coordinate system called Talairach coordinates [3]. Neuroscience employs both approaches for representing the cerebral activation areas over functional magnetic resonance images (fMRI) [4,5].

II. METHODOLOGY

Cerebral activation data associated with emotional stimulus, such as repugnance, fear, sadness, happiness and anger, are not widely available. The main reason is that fMRI exams are expensive, what makes difficult their use in large scale applications. Besides, this type of exams demands extremely controlled procedures and specialized equipments. This problem can be solved by using reliable data provided by renowned research centers.

This research uses fMRI data from databases and atlases listed by the UCLA Laboratory of Neuro Imaging [6]. These data are acquired though controlled exams where emotional cerebral activation is isolated from other activations such as vision, olfaction, stress, etc. The procedures for this acquisition are not part of the scope of this paper.

Another constraint was normalization. Once data are generated from different human samples, it was mandatory to apply spatial transformations in order to perform an adjustment based on a default brain model. The adopted model is the one proposed by the Montreal Neurological Institute.

Under this exiguous data scenario, it is necessary to allow the access to as much data as possible, no matter in what format the data is available. For this reason, the implemented methodology permits the data acquisition on several formats, such as volumetric images, Talairach coordinates (TC), and Brodmann areas (BA). Figure 1 schematically illustrates the methodology phases to obtain a computational model for cerebral activation dynamics submitted to emotional stimulations.

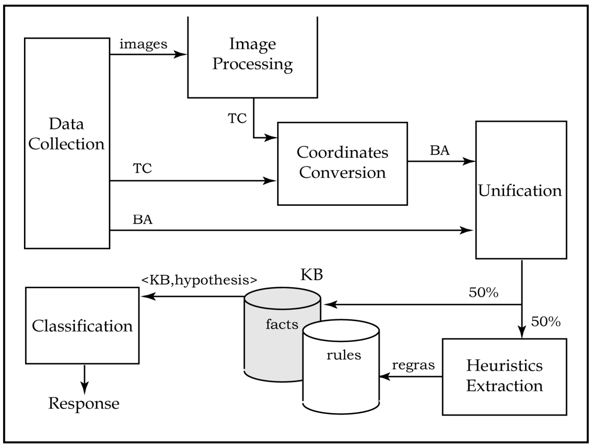

Figure 1. Methodology's block diagram used on the cerebral activation processing.

Considering the volumetric images, it is necessary to define Brodmann areas associated with activation. This task is accomplished during the image processing and the coordinate conversion phases. The former is responsible by the activation center calculation, and the latter is dedicated to locate the corresponding Brodmann area. The data codified by Talairach coordinates are processed just by the coordinate conversion phase so as to identify the region which inscribes the activation point.

In this study, the Talairach coordinate would not be adequate because of its punctual nature, which disguises the error. One might assume that the associated activation occurred exactly at the point indicated by the coordinate, which is not true. The coordinate is defined by a human operator whose expertise subjectively suggests an activation point. If the same human operator had a second chance to indicate the activation point for the identical region, he would probably define a point near the previous coordinate. In fact, one of the disadvantages of using this kind of representation is the absence of a neighboring interval value.

Brodmann areas and volumetric images, on their turn, naturally present an associated error caused by the uncertainty of the neural activation. Therefore, the Brodmann areas labeling was chosen for tagging locations due to its relaxed precision [7].

The unification phase corresponds to a data conformation, whose objective is to prepare the obtained data to be represented by logical facts in order to be inserted into a knowledge base (KB). The heuristics extraction is concerned with the search for the identification of production rules that describe the different relationships among the activation volumes during the dynamic cerebral activation process. The number of image frames per test case depends on the medical procedure used to evaluate activation regions. The process described in this paper uses all frames provided by image databases and electronic atlases, no matter how many of them are provided.

A Turing Machine was used for emotional state recognition, represented by finite automata. The use of Turing Machines is important since those mechanisms are widely known and accepted as algorithm formalization. Besides, it has at least the same computational power of any electronic device, which allows us to ignore any technological dependency. The identification of such machine, among a sampling space, suggests the existence of a systematic treatment of the problem, that is, it indicates the possibility of constructing a computational model to solve the representation of the brain mechanical activation.

Finally, the classification phase is responsible for identifying an emotional activation sequence. This identification process consists of performing computational derivation from a hypothesis based on the knowledge described by facts and rules [8]. Hence, if the proposition is proved by the oracle, it is possible to assert what the corresponding emotional value associated with cerebral activation is.

III. Coordinates Extraction From Volumetric Images

The main goal of the image processing phase is to define a cerebral activation mathematical center associated with volume activation from a volumetric image. It should be observed that this procedure adds error to the methodology as it generalizes a volume into a mathematical point. However, this error can be minimized since the point will be used as a reference to locate the Brodmann volume which encapsulates the punctual activation.

Cerebral function uses several brain regions, which means that one function might use many Brodmann areas at once. Thus, one volumetric image might contain one or more activation simultaneously. The volumetric image is segmented in order to separate all activation volumes. This segmentation is performed by using geodesic snakes [9,10], which guarantees the location of all activation volumes into different bounding boxes. At first, it is applied a geodesic snake in order to define the skull's contour line. Then, this line is shrunk and used to initiate another segmentation using the same geodesic snake algorithm. Figure 2 illustrates a volumetric image with eleven activation volumes, being one of these volumes highlighted by its corresponding bounding box.

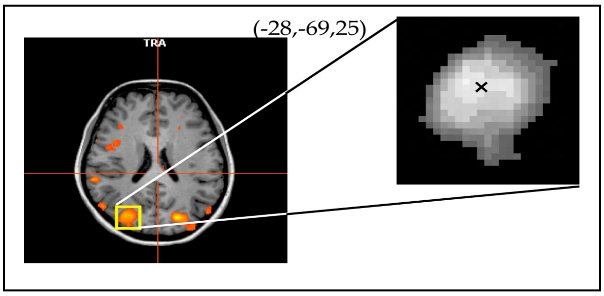

Figure 2. Cerebral activation volume and the determination of a mathematical activation point.

Once the activation volume is segmented, it is required to compute the activation center. Considering the highlighted volume in Figure 2, one can assert that there is no uniformity in the activation intensity. This phenomenon is indicated by the different gray levels, correctly suggesting that there is an activation gradient on the region of interest. Brightener regions are more active, and thus should contribute more significantly than those less active. This feature is captured by the activation center calculation is given by (1).

$$P_C = \frac{\sum_i a_i P_i}{\sum_i a_i} \tag{1}$$

The equation (1) shows the relative contribution of each activation volume fragment by computing the weighted mean position value for all voxels. One should observe the similarity between this calculation and the center of mass determination used on classical Mechanics. The value P_i represents the voxel coordinate; a_i is the activation intensity; and the coordinate system corresponds to the Talairach System.

IV. Coordinates Conversion Into Brodmann Volumes

This stage aims to find out the Brodmann volume which inscribes a coordinate, that is, the activation point. Unfortunately, the authors noticed that there are no computer tridimensional models for human brain divided into Brodmann volumes, which pointed out the necessity of creating such model. During the collection of images to be used on the computational brain model construction, the authors realized that all medical literature references converge to an old book by Sperry *et alli* [11]. From this reference, three slice images were obtained (see Figure 3), scanned, and used to construct vector images. Then, these vector images were spatially transformed in order to be registered over Montreal Neurological Institute default brain surface model, which is used by scientific community as a reference model to avoid the brain size variations and deformations.

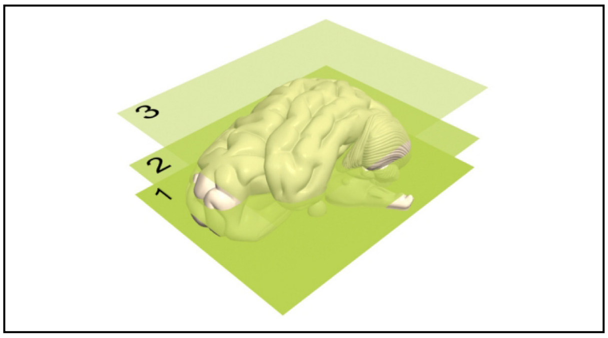

Figure 3. Brain slice images position from Brodmann areas snapshots.

The Brodmann volumes model is defined by using the planar vector images and a morphing procedure. In Figure 4a, two planar objects (a disk and a star) are used to define the shape from the initial and the final limits of the tridimensional model. Then the morphing procedures produce a tridimensional model where the initial shapes change into the final shape through a seamless transition. For instance, Figure 4b illustrates two slices from Brodmann area 06; the tree dimensional model for this region; and an illustrative overlap between the obtained model and one original slice raster image.

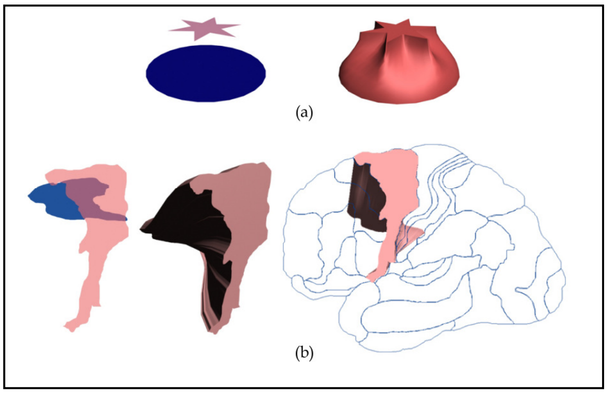

Figure 4. Morphing procedure used to create Brodmann volumes.

Once Brodmann volumes are defined, it is possible to identify the region which inscribes the activation point. This research uses a modification of Computer Graphics collision detection [12] routines with the purpose of verifying if the point is located inside the negative semi-space defined by each geometric primitive that compose the three-dimensional model shell.

V. Knowledge Base Construction

The unification is responsible for preparing all the information obtained through the Broadmann volumes identification stage in order to be represented as propositional facts of a knowledge base (KB). The heuristics extraction corresponds to the production rules determination. Those rules represent the different relation among the activation volumes during the dynamic cerebral activity process.

The emotional states recognition is performed by a Turing Machine, represented by finite automata. This kind of approach is quite interesting because those machines are known and accepted as algorithm formalization. Besides, Turing Machines have at least the same computational capacity of any electronic device, which allows avoiding any technological dependency. The identification of such machine proposes the possibility of a systematic treatment to this problem, that is, the feasibility for constructing a computational model capable of solving the brain mechanical activation modeling problem.

In this work, we represent the activation volume by using alpha-numeric symbology. The first two characters of this representation are filled with the same number of the Brodmann volume. The third and last character represents the brain's hemisphere. For instance, the Brodmann volume 23 for the right hemisphere is represented by the symbol 23D. Figure 5 illustrates an automaton associated with modeling of the anger process, beginning at q_0 state, where all Brodmann volumes are deactivated.

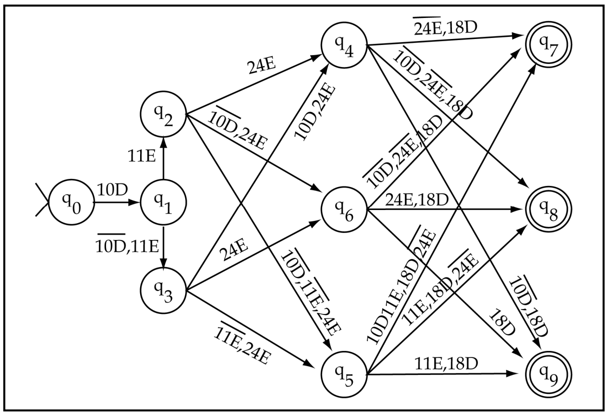

Figure 5. Finite automaton representaing the state transition for a system recognition associated with anger emotion.

VI. Classification Results

The classification stage identifies the emotional value associated with an emotional activation sequence. This identification process consists of a predicative hypothesis computational derivation according to the knowledge base facts and rules. Therefore, if the proposition is confirmed by the inference machine, it is possible to assert that the emotional activation sequence was identified.

The sample collection was composed of 74 exams: 17 volumetric images, 38 Talairach Coordinates sets, and 19 Brodmann areas sets. These data represent a collection of fMRI exams of people who were submitted to emotional stimuli such as fear, happiness, sadness, anger and repugnance. The recognition Formal System is capable of identifying these emotional states.

The exams were divided into two groups. The first group had 37 exams, and was used to perform the heuristics extraction. The second group was the testing sample and also had 37 exams, as illustrated on Table 1. Among all these testing samples, just two of them could not be deducted by the inference machine, which means that the implemented methodology achieved 94.59% of success on recognition. Those failures occurred because of the insufficient number of exams used during the heuristic extraction phase, which was not able to capture all possible production rules.

TABLE I. Exams description

Emotion	Number of Exams		
	Heuristic Extraction	***Testing***	***Successful Recognition***
Anger	3	2	1
Repugnance	5	4	4
Sadness	7	7	7
Hapiness	7	7	6
Fear	15	17	17

VII. Conclusion

This paper demonstrated how image processing, computer graphics and computer theory can be useful on emotion recognition. It was shown a pattern cerebral activation recognizer Turing Machine, derived from functional magnetic resonance images, in order to systemize the cerebral activation human process for a limited set of emotional stimulations.

It was explained how to locate volumes of interest over a computational model by using volumetric images and mathematical coordinates as input data. Moreover, it was described how the computational reference model was obtained from ordinary raster images. The pre-processing procedures contributed significantly to satisfiable results on emotion recognition.

In future works, we intend to increase the number of exams used on the heuristics extraction stage with the purpose of enlarging its representability. In addition, it would be interesting to model not only primary emotions, but also the secondary ones.

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