International Journal of Research in Pharmacy and Biosciences
Volume 2, Issue 5,June 2015, PP 38-48
ISSN 2394-5885 (Print) & ISSN 2394-5893 (Online)

# Executive Functions as Virtual Machines: A New Metaphor for a Neuropsychological Classic Concept

**Julián Marino[a,b,c], Rodrigo Jaldo[a], Fernando Gabriel Luna[a], Juan Pablo Zorza[a], Gustavo Foa Torres[a,c,d]**

[a]*Laboratory of Neuroimages Processing, National University of Córdoba, Córdoba, Argentina. Enfermera Gordilloesquina Enrique Barros*
[b]*Cognitive Neuroscience Research Group, University of Granada, España. Campus de La Cartuja S/N*
[c]*Private Computed Tomography Center Córdoba S.A. –Oulton Foundation, Córdoba, Argentina. Av. VélezSarsfield 562*
[d]*Medical Sciences School, National University of Córdoba, Córdoba, Argentina. Enrique Barros S/N*

## ABSTRACT

In this article, Executive Functions (EFs) have been analyzed as a metaphor of brain activity. A new metaphor is proposed: EFs as activation of scenarios or virtual machines. This proposal will be sustained with explanations, and experimental data. The EFs concept transcends the information produced by classical cognitive capacities, such as attention and memory. By “transcending” us ethymologicaly understand, something behind or above the scene, and into neurocognitive domain means that it is a superordinate entity. Then, that EFs are superordinate implies they are on a different level, regarding the aforementioned cognitive abilities, but: how does this phenomenon occur? We present evidenceto sustain that the EFs most appropriate metaphor is 'the generation of virtual machines'. Evidence and benefits of using this new EFs metaphor will be presented together with the richness of relationships generated by the cognitive activity illuminated by this metaphor: the closeness with the concepts of self emotional regulation, effortful control, temperament and personality will becleared; as well as the cultural influence of the “Executive” metaphor has been highlighted.

**Keywords:** EXECUTIVE FUNCTIONS – CLINICAL NEUROPSYCHOLOGY- PREFRONTAL CORTEX-METAPHORS- COGNITIVE CONTROL- CROSS CULTURAL NEUROPSYCHOLOGY Abbreviations[1]

## INTRODUCTION

### An Analysis of the Executive Functions Metaphor

Executive Functions (EFs) implya metaphor of brain functioning. The analysis of a metaphor in the context of traditional Aristotelian system has the following structure: each metaphor has a topic, a vehicle, properties transfered from the vehicle to the topic, and the role ofanother metaphor, the 'cognitive colonization'. This type of analysis is still used in cognitive psychology (Vega Rodríguez, 1984). The implications on this analysis result in the increase of knowledge on the topic, due to the transfer of some of the vehicle’s structural properties into it. However, there must be – between both topic and vehicle- a superordinate categorical difference, in the same way that saying that a train is like a car does not constitute a metaphor. In the Aristotelic metaphorical structure, complements are supported as circumstancial of mode, place and time; whereas in the analysis of EFs as metaphor (of the prefrontal cortex functioning), the topic is “cognitive function”, which makes reference to the vehicle “executive”. The metaphorical transfer of “executive” to a set of cognitive functions is what would apply for an executive chief, a manager or businessman (Lezak, 2004): the ability of reaching concrete goals, maintaining sets that represent joint interests, directing subordinates, implementing plans, and coordinating complex systems (as in an enterprise, isn’t the brain an enterprise of evolution in order to adjust and create the world?) In the EFs metaphor, the expression “cognitive colonization” makes reference to an article that exceeds the fifty years of age.Alexander Luria (Stuss, 1992) used

[1] VM(s): Virtual Machine(s)

***Address for corresponde***

jmarino@psyche.unc.edu.ar

the executive metaphor to refer about the functionality of the prefrontal brain region (Ardila, 2008). Before this, the prefrontal region was considered as a'silent' brain area. In the early twentieth century, neurologists did not know clearly the effects of an injury there (Anderson, Jacobs, & Harvey, 2005), beyond some clinical strokes as the famous case of Phineas Gage (Damasio, Everitt, & Bishop, 1996). The metaphor of the EFs was used to assign the overall functionality of the prefrontal brain region, when it was unknown. The cultural and social dependence was noted by Alexander Luria. He found that farmers in Tatarstan who were investigated and treated clinically had no symptoms. But similar lesions meant significant clinical relevancein an executive businessman living in the complex cityof Chicago (place of residence of Muriel Lezak). Therefore, the metaphor of EFs also implies a cultural bias towards Eurocentric North American- functionalism, which includes the determination of the individualistic sense of life.As a brain property, which means a translation into brain function, EFs were originated in the USA culture. We intend to pint out the abuse of metaphoric language level, regarding the use of EFsas the same of the 'body logic' language level (Sugarman, 2002). The proposal of EFs cognitive colognized by the metaphor of virtual spaces generated by interconnected layers has less cultural bias and may show higher fertility. But it should be demonstrated. Under this background, it is necessary to review together the concept and metaphor of EFs.

Muriel Lezak (1980, 2004) systematized the definition of EFs in the so called 'Bible of Neuropsychological Assessment'(Lezak, 2004) and established four basic characteristics: a) EFs are a set of functions that allowindividual independence, b) Theyachieve their self – determination, c) the set seeks to achieve goals, and d). It organizes the remaining cognitive abilities. Then, the author made an inventory of multiple and heterogeneous neuropsychological techniques for measuring EFs that clearly showed the rising opacity of theconcept, stretching from latching tasks as Mecano, verbal fluency and Rey Complex figure. This broad definition experienced a 'trade-off' between its usefulness, novelty and its ambiguity and extension. There were a lot of candidates to join the EFs, including mechanisms, sub-functions and components. Since then, it has been considered an 'umbrella' concept(Chan, Shum, Toulopoulou, & Chen, 2008), under whose protection other concepts of notorious diversity found a refuge. Among these,may be mentioned cognitive flexibility, inhibitory control, working memory, planning, sequencing, goal orientation, self-determination, monitoring, concept formation, decision making, effortful control, self-regulation. If this list is carefully analyzed and the history of each one is reviewed, it can be noticed that the concepts correspond to different levels of analysis (the person, the cognitive system, a mechanism, a function), and are neither exhaustive,nor mutually exclusive. Some are nested, such sequencing is within working memory mechanisms and goal orientation is a part of decision making. Complex relationships were also detected between these concepts to solve close conceptual "neighbors", such as effortful control and self-regulation. They are near to EFs, but it is not easy to identify the boundaries between these concepts and to establish a path of causal relationships. In this context, Sugarman (2002) summarized: after years of research in EFs, why do our tools remain empty?

## The Introduction of Neuroimaging and Tasks for the Conceptualization of Executive Functions

Therefore, the classical concept of EFs as a superordinate entity oriented to control and goal-reaching was fertile, but also caused problems that needed to be solved mainly by the aforementioned semantic and technical ambiguity. When the functional magnetic resonance imaging (fMRI) studies emerged, new 'temporary' difficulties arose: how to recognize when EFs were activated and when not, in an accurately and reliable manner? Could a cognitive ability be activated/ deactivated or was their presence constant? Would someone doubt that the liver is always present in the living organism…Could this be said about memory? The neural structures (organ logic) arealways active, in an ontological sense.But, is the cognitive processactive/inactive, or 'is' in the same way that the liver ontologically 'is' (persistence, structure, function)? Is the attentional control present as body language (registered in time and place) or is it activated/ deactivated when receiving a call or a callback? The contributions of magnetic resonance imaging (MRI) have been crucial in order to address these issues. There were classical tasks (e.g. Wisconsin Card Sorting Test, Trail Making Test) that were proposed as classical measures of EFs,and have not elicited signs of hemodynamic changes in some experiments, when that was expected(Yue, Lindquist, & Loh, 2012). It can even be found some mention to the 'elusive' nature of the EFs when considering its neurofunctional activity (Jurado&Rosselli, 2007). In addition, other tasks that traditionally were not associated with EFs, like learning words lists under the Lezaksystems of word recall memory, did reported supplemental oxygenation in neurovascular couplings of prefrontal areas. This prompted the meta-concepts for EFs (Barkley, 2012), and that in the time dimension, albeit implicitly, activation prevails over continuous presence allotted to the structure presence ('organ language logic'). In fMRI studies, the concepts associated with tasks of EFs activationshowed if the task resulted easy or not for the person (hard = hemodynamic prefrontal demand of suppletoryhemoglobyn). Then, a learning effect (meaning no activation), the need for concentration (concentration = activation), the importance assigned to the task (more important = activation) and the involvement of new learnings, changed the structural, functional and cultural concept of EFs to a more dynamic flow of efervescence of thermodynamic ramifications in neural networks. In a recent study,Stillman, Van Bavel, & Cunningham (2014) noted that the importancean individual attributes to the goal of a task determines a mobilizing amygdala activity when positive stimuli are presented: if you can not attribute relevance to the task, positive stimuli cause no hemodynamic changes. This means that the genaration of mobilization depends on how important the goal is rewarded. The reward relevance depends partly on variables as motivation, making the clinical assessment of EFs more difficult.

## A Classical Model of Executive Functions: The Main Role of Three Functions

The work ofMiyake et al. (2000) had a remarkable significance in clarifying the concept of EFs (to check this story it is recommended the reading of Barkley, 2012). Miyake and collaborators used dimension reduction multivariate techniques and concluded that the EFs were composed of three basic functions: inhibitory control, updating of working memory, and the change or cognitive flexibility. Critics to this study have arised since, due to its confirmatory logic design; it began with nine tasks chosen a priori, although there were a large amount of EFs tasks. The choice could have an arbitrary hue. But its popularity was objectively measured by the number of quotations, which are more than 4500 to the present, indicating that the crucial problem of 'umbrellaterm' of the EFs had been faced. Otherwise, it is likely that the choice of'confirmatory' techniques had more critical receipt. From its "Occam's Razor", in several studies new EFs were proposed, but in order to be added to the three basic factorial models. For example Östberg, Fernaeus, Hellström, Bogdanovic, &Wahlund (2005) added the action fluency as the fourth component. Despite the remarkable number of similar examples, the importance of the work of Miyake and cols is laying the groundwork for EFs on a consolidated set.

The metaphor of EFs centred as superordinate control- oriented to goals entities, has allowed adding some emphasis to the ontological and computational differences between EFs and cognitive abilities. Cognitive abilities have settled functional properties of nodes and networks of white and gray matter in the cognitive approach near the classical concept of modularity and representational theory of mind (see Fodor, 1983). Instead, EFs (now inhibition, cognitive flexibility and working memory updating) act as higherentities. In computational and neural networks, EFs made sense as the knot of a massive number of connections. However, would this featurebe activated as long as modules were? Such as the mnesic registration, the use of language, and the visuospatial attentional alert, couldthey be located in time? How does this influence the concept of the EFs? Is cognitive flexibility a property or is it ability? Do the control ontological signalsincrease effort? How do they relate to the basic EFs? Howdoes temperament and inhibition relate to the EFs? These questions will have great difficulties encountering the metaphor of the EFs as an 'executive' of the brain. The temporal and spatial dimensions of the EFs have as well brought some problems.

## The Temporality of the Cognitive Functions

The metaphor of the EFs as virtual spaces or machines believes that the mind is partly a 'virtual machine', and partlya system that might be susceptible to physical descriptions. The tractography images by Diffusion Tensor Imaging (DTI)(Leemans, Jeurissen, Sijbers, & Jones, 2009) allow precisely to visualize knots axons that connect the brain in a large scale, and therefore displayed structural connectivity between the zones associated with each ability. However, Kalisch (2009)showed that only the active interface (functional connectivity) of cognitive abilities allows more complex activities. In his research, he focused on how the reappraisal of negative emotional events occurred with effect in reducing the impact of the amygdala to produce aversive emotions by changing meanings about the emotional impact. When participants performed reappraisal, massive hemodynamic changes were observed in the cerebral cortex, simultaneous to when the 'storm' of activity in cognitive abilities was produced. However, he also found that only a few people could perform this task (reappraisal) successfully, and that it was related to the ability to maintain affective episodes in the working memory for a long time without distractions. In his experiment, the task began with a recovery of episodic memory and succeeded by the activation of the working memory level. Questions of this work on temporality of EFs were: was episodic memory of the event under body language or computer language, or both are compatible in terms of the existence dimension of temporality ($t_1 \rightarrow t_2 \rightarrow t_x$)? What differences does exist in enable/disable between episodes of episodic memory with the effort of working memory depending on the existence ($t_1 \rightarrow t_2 \rightarrow t_x$)?These are questions that relate to what you seek then on the language of psychology, in line with Lisa Feldman Barrett (Barrett, Lindquist, & Gendron, 2007; Barrett, 2009).

According to the 'cascade' model of EFs(Koechlin & Summerfield, 2007), the subsequent activity of brain areas is regulated by signals sent from above prefrontal areas in the brain, stratified from (posterior to anterior) motor, contextual episodic and pending signals. It is possible that this model has not accounted a place to include affective signals. The lasts are related with some of the called 'neighbour' concepts in the EFs domains. For example, when a noticeable difference between what it is running and what it is expected of an action hits a sign of emotional alarm, the anterior cingulate cortex is strongly committed to cause 'psychic pain' (Shackman et al., 2011). Then the alert signals tell us to make a change in the action execution. In classical language of EFs, monitoring and inhibitory control were activated. Also, cognitive flexibility is considered a basic EF, related to temperament and personality traits. The lasts are considered stable rules of behavior, or simply, traits. Then, people receiving an alert signalfrom the anterior cingulate to detect conflicts(Botvinick, 2008)differ in their responses because their different copying styles derived from traits. Increasing the cognitive effort allows the generation of anticipation strategies for possible future conflicts. For these reasons, it is becoming clear thathuman activity generates gradual activation of 'cognitive spaces' that is, flexibility, inhibitory control, and working memory amplitude. The role of effortful retrieval, temperament, alarm signals, could be related with general effort and goal aligned settings, affecting up to the perceptual level via computational flexibility of the gray and white matter fronto-parieto-occipital networks(Botvinick, 2008). These 'cognitive spaces', could be composed of something called executive Virtual Machines (VMs). A virtual machine is an operating system that is added to a computer that used another operating system, and it allows the addition of new processing softwares, without altering the machine language.

In the study of the 'default network' (Fassbender et al., 2009), it has been seen that humans '*roam the world*' with a self-referential mental inertia to review past events with a positive or negative emotional connotation, commonly recent. In the default mode brain function, there is no goal orientation and the solving problems machine is turned off. This is called 'mind wandering' (McVay & Kane, 2012), and it results as a 'comfortable' inclination. However, warning signs from emotional and mental pain assault the 'mind wandering' set. According to variables related with personality, temperament and education, it is possible that the virtual spaces of the EFs in these affective events (Zorza, Marino, Lemus, & Acosta Mesas, 2013) would be activated. Emotional signs, conflicts, alarm signal and effortful (control?) would be linked to the need of amplifying the mental space. The effective response is to activate VMs placing the basic EFs at service.

This would indicate the close relationship between notions of temperament as effortful control (Rueda & Cómbita, 2012) and EFs. The effortful control in early childhood is associated with inhibitory control, avoidance of distractions, and wish procrastination (Rueda, 2012). These temperament traits were closely linked with the use of emotion regulation and executive control, the higher level of these, more effortful control in childhood and adolescence (Posner, Rothbart, Sheese, & Voelker, 2012). In this line, the metaphor of the EFs as VMs involves coordination with the effortful control. The effect would be a representational 'synesthesia' (synesthesia as a metaphor)between different cognitive abilities that trigger layers of processing more efficient through greater inhibition fluency in working memory and greater connectivity - flexibility. Before this effort, these virtual machines 'were not' generated, because these are high costly to the brain- mind machine, which treat to reach the more effective functioning at low cost possible ($t_1 \rightarrow t_2 \rightarrow t_{vm} \rightarrow t_{3\ \text{process 1 level1}} \rightarrow t_{vm2} \rightarrow t_{4\ \text{process1 pass to level2}}$).

To continue with the differentiation between cognitive abilities and EFs, visual brain areas located in the occipital cortex process differences between lines, shapes distinguish narrow gaps and communicate with temporo-parietal conceptual areas via the arcuate fasciculus. By structural and functional connectivity intermodular, it comes up the labeling process where the lexicon meets visual figures (Catani & Thiebaut de Schotten, 2008). The psychological language (visuospatial processes, labeling processes, output lexicon of speech) represents an obstacle to acquire more accurate psychological words because it carries sediment of ancient philosophical language that comes from the requirements of the faculties of the soul (Mora, 2001). The Canadian psychologist Lisa Feldman Barrett (2009) made a call to a new language consisting of psychological primitives. She promotes the metaphor of psychological primitives as ingredients in a cooking recipe. The development of cognitive ontologies, aligned with this idea and with the contribution of neuroimaging (inverse inferences) promotes overcoming semantic difficulty caused by the customary use of cognitive abilities such as attention, memory, language, that are centuries old. An ontological review of the matter can see in Poldrack (2006). Projects like COGMAP face this challenge (Storm & Bui, 2015). However, the psychological primitives proposed by Lisa Feldman Barrett claim that ontologies as COGMAP even use the metaphor of the EFs at the same level of cognitive abilities. Therefore, it would be questionable to be treated as an effective ontology of mind. Rather, it seems like an ontology protocol, respecting the published experiments. But the progress of the foundations of a knowledge engineering of cognitive concepts needs new feed.

The metaphorical synaesthesia of VMs representations produced by cognitive abilities retrieves the EFs coordinated capacities from issuing signals described as 'Q' as cognitive control in the classical language of the theory of information processing (Koechlin & Summerfield, 2007).Retrieving the informational language of mental computation can be useful to this complex problem. The Q signals are output from prefrontal hubs or nodes, following an anterior-posterior sagittal brain direction. To be activated to anticipate possible differences between the observed and expected world stimulus, it follows the way to automatize strategies that progressively solve the question without effort. And thus avoid having to keep running the most complex and debilitating brain activity: (t1→t2→tvm1→t3 process1 level 1→t3 process 1 maintains level 1).

This raises the need to understand the brain-mind system from a more complex perspective, strata/layers that are activated as virtual spaces that may appear or be off. This plays a crucial issue in determining psychological capacities, referred to their existence in time: cognitive capacities temporal ontology of 'being'. Some capabilities 'be' ($t_1 \rightarrow t_2$) in the sense of spatiotemporal continuity, but EFs seems comfortably with turn off binary model of existence. What can we learn from the recipe Barret's metaphor? While body structural-functional language has a map with regions, mind activity appears ontologically temporal-sensitive.The locations of the brain organ, e.g. gray matter in the left lateral orbitofrontal cortex and frontal white matter fornix, are traceable to structure level ($t_1 \rightarrow t_2$ continuity); but faced with the 'Barrett' problem about the precariousness of psychological language to describe the processes of the mind, as, for example, the decision of the depressive individual to get up from bed. In psychological terms, it seems like aneffervescent storm of ingredients burning in a cauldron which ends in a tree form process.

## The Executive Functions in the Cascade Model: The Role of Virtual Machines on Cognitive Control

To unravel this problem it is necessary to move the EFs computer metaphor and remove it from its original cultural context, characterized as a western functional executive individual. Koechlin & Summerfield (2007)conducted an approach to the EFs as an emerging cognitive control by signals formalized through language information processing. For these authors the relationship between's' (stimulus) and 'a' (action) (s│a) (remember the Bayesian notation) implies a gradual need for 'Q' (cognitive control). The relationship s│a represents the modular operation, because it enters's' and an output value 'a' is delivered. It resembles the partial 'stupid' systems (sic) described on Marvin Minsky's 'The Society of Mind' classic book (Singh, 2012). To Koechlin& Summerfield, context requires the selection of an action that requires an amount of information H (a), to calculate H (a) = -$\log_z$ p (a). It follows that if H (a) obtained a value of 0 (zero) then the probability that 's│a' lead to one action is equivalent to p (a) = 1. In this case the activation of VMs is not necessary. The person may operate by 'default'. However, as 'p' approaches 0, the probability that 'a' is chosen by chance, or only influenced by the context 'c' decreases. The requirement for 'Q' appears increased. The link between s│a is represented by the term 'link' = l (s│a). When l (s│a) = 1 then H (a) = 0. This implies a sensorimotor control. However, when Q (a│s) = H (a) - l (s, a) then p = -$\log_2$ (│s), this implies that the choice of (a) requires cognitive control Q. Obviously, the less predictive offer's' to 'a' increases the amount of Q (a│s) plus the link l (s│a). So the term 'c', which involves the amount of additional contextual, cues 'c' that must be implemented to link [l (a│s)] influences H (a). Therefore, the amount of cognitive control [Q (a│s)] will equal the link [l (c, a│s) + Q (a│s), c].

Independent ‘c’ signals are especially relevant for the metaphor of VMs. These additional signals are independent of the implementation s│a, required for implementation of Q (a│s), c. This would affect the contextual control that exceeds the notion stimulus response, however, the 'Q' (cognitive control) can be decomposed in the link [l (u, s│a, c)] + Q (a│s) c, u], where the new signal 'u' refers to episodic signs preceding the implementation of the signals 'c' and the [s│a] implementations. It is relevant that the hierarchical 'cascade' model establishes ranks of signals from u,c,s to reach an action selection. The model of action as the clue of the brain in function can be tracked from the pragmatic notions of William James to Karl Popper (see the discussion between Popper and Eccles about the self and the brain). The signals 'u' are episodic in nature and belong to learning that are implemented to complex-up the action selections to achieve a layered control. It is particular interesting that Koechlin & Summerfield (2007) established that the occurrence of signals 'c' andBoolean notation signals 'or' demands previous activity of the prefrontal cortical areas. All of this is the 'unwanted' by default cognitive functioning, as they involve high energy expenditure.

Solving a problem involves the difference between an observed state and a desired state (Newell & Simon, 1972). When a person focuses on a problem, it inhibits possible alternatives to reach the goal. This involves the use of signals [s (u, s│a, c)] + Q (a│s), c, u]; however, the metaphor of VMs implies that [l (u, s│a, c)] + Q (a│s), c, u] = $Q_1$. $Q_2$ takes [l (u, s│a, c)] + Q (a│s) c, a] = $Q_1$ as a cognitive ability, just as timing that $Q_1$ signals sent cascaded laminated on cognitive abilities. It is well understood and better than cognitive flexibility, inhibition and updating of working memory as functions that operates without knowing when. From VMs metaphor, cognitive flexibility could be the product of the enlargement of the mind working space. In the traditional neuropsychological literature,several studies used the part B of the Trail Making Test as a typical task of cognitive flexibility that meant moving to join the number 1 to the first letter 'a' and then following the sequence of numbers and letters. However, this same task was considered as a 'dirty task ' (Chan et al., 2008), such as might be interpreted in psychomotor speed, sequencing, and attentional focus. The metaphor of the EFs VMs implies that a task measures only EFs if these are stimulated, but there aren´t an 'essential form' of tasks to do that. It is possible that individuals utilize the EFs in a more intense way to solve certain tasks, but it would be impossible to depart from a0 EFs degree.Reasonably, a VMs model of EFs climbs commitment to 0-1 according to the number of virtual machines that are activated. Table 1 represent the main symbols used in formulas and it conceptual explanation.

**Table1.** *Main symbols and it conceptualization in the cascade model analysis.*

| **Symbol** | **Concept** |
|---|---|
| H(a) | Total amount of information required to perform action 'a' |
| ‘a’ | Selected Action; action ‘$a_{xlevel}$ depend of the observator analysis; x level of ‘a’ comprehend the observer selection of ‘action of interest’: a1, a2, etc. |
| p(a) | Probability ranged 0-1 that ‘a’ $_x$ action would be selected |
| ‘s’ | Stimulus; determination that also corresponds to a scientific frame observer |
| l (s│a) | Relationship between implementing a given stimulus, the probability that an action occurs automatically' ($a_x$); ‘l’ implies the 'link' or connection between the two elements, the basics in psychology history also known as sensorimotor control |
| P(s│a) | Probability that once an ‘s’ stimulus was presented triggered automatically the $a_x$ action; clearly this relates to the power of l (s│a) |
| Q (a│s) | Quantity of cognitive control ‘Q’ necessary to address the relationship between actions and stimuli |
| ‘c’ | Contextual control is added necesarally to the selection of actions = l (s│a), c. Isn´t a minor question signals added context |
| ‘u’ | Episodic control, forward information stored in long term memory sub systems is added to the formula= Q (a│s, c)= l (u, a│s, c) + Q (a│s, c, u). Important: the episodic control needs the episodic buffer of working memory to connect on line process with memory data warehouse. |
| $Q_2$ | Implies one key of the original contribution of virtual machines metaphor activation of cognitive control, because Q (a│s,c)= l (u, a│s, c) + Q (a│s, c, u) *but$Q_{2\ trascends}$* [$Q_1$] then = $Q_2$ [Q (a│s,c)= l (u, a│s, c) + Q (a│s, c, u)] |

Table 1 has presented $Q_2$ p $_{[Q\infty]}$ that refers to activation of VMs. $Q_2$ adds to the Koechlin& Summerfield cascade theory a multi-layer activation of virtual stratum containing within this activation that is known as classical EFs within the west executive functional cultural metaphor. But, considering VMs metaphor, while increasing the number of VMs, it will be higher the level of effectiveness of these EFs. Figure 1 represents the introduction of VMs in the cascade model.

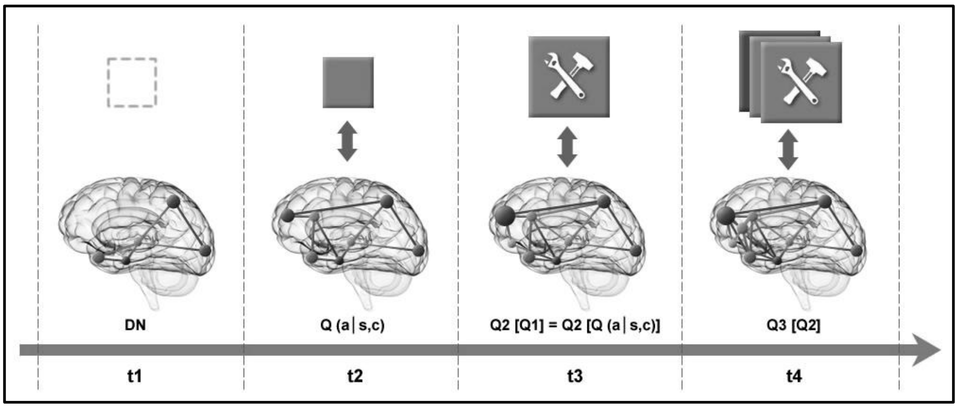


**Figure1.** *The temporality of processing and the amplification of virtual scenarios for working*

To achieve the empirical grounds of these speculations, controlled studies linking behavioral tasks (reaction times and 'accuracy') are needed.Also, measurements of emotional activation dimension, effortful control, motivation, alertness signals, emotional regulation, psychic pain and ongoing task of relevanceperception needs to form part of the experiments too. The metaphor of VMs ($Q_2$→ $Q_3$→ $Q_\infty$ [Q]) would mean the possibility of transcending beyond the information itself. The neuroanatomical pattern indicates a super-entity in the prefrontal region that metaphorically acts as a central executive (Baddeleyand Schallice classic concepts also see Fuster works). But from this perspective VMs would be linked to motivational, temperamental, emotional, psychic pain, alertness constituents embedded in neural networks, cognitive capacities, genetics expression, and socio economic instation (?) of interpersonal interplays, educational concrete practices of learning and cultural creation of goals.

## The importance of the new conceptualization of Executive Functions as Virtual Machines

As nearestgoal we consider writing an essay, promoting VMs metaphor as an enhancer for the role of education, learning and brain-mind as a prediction system designed to 'avoid future mistakes' and build the world. The second section of such essayshould is a criticto EFs metaphor centered on individual goals and its extrapolated body language level that dangerously mingled cultural lifestyles with mental-brain organization. VMs act expanding mental spaces via motivation, temperament, training, and learning. The key that represents this activation of parallel computing via temperament, effortful control and learning are allied where Q signals are emitted in cascade, and its counterpart or loan is the effort involved. VMs indicate that EFs amplify and decrease, being more or less active, as well as practically absent by default and well learned action pathways. But EFs are recruited when an episodic, prospective, emotional, cultural warning signal needs to improve the use of the cognitive capabilities (Marino, 2009). This would also have implications in clinical neuropsychological assessment: the way EFs as VMs metaphor predicts they are activated in a greater or lesser extent, would be less task-dependent.Namely, there wouldn´t beEFs tasksas the same manner are patterns of recognition and naming pictures, since the EFs woulntd not allow measureme in the same way that cognitive abilities do.

In a theoretical approach to the computation of EFs, their hierarchy is highlighted. The metaphor of VMs must be anatomically completed, along with the architectural design of the mind. A remarkable result appears at this point: there will be EFs tasks that would be enabled with VMs. There would be tasks that could do so in an easier way. As noted, it has been shown that the amygdala, an emotional mobilizer, emits signals to positive stimuli interpreted only if the task has relevance in terms of specific goals. If the person believes that the task has little relevance, the task don´t activate VMs. But, also, it would be difficult to find a test not involving in any degree the FEs. Even its measurement could be in a nested level, it is associated with neuronal connectivity: there are massive nodes of gray matter located in the prefrontal brain regions (Fuster, 2004) receiving afferent tracts (see Figure 2 for an illustration): prefrontal thalamic fibers, the fornix (Catani & Thiebaut de Schotten, 2008), the superior longitudinal fasciculus(Thiebaut de Schotten et al., 2011), the uncinate fasciculus (Von Der Heide, Skipper, Klobusicky, & Olson, 2013), the anterior cingulate cortex (De Pisapia & Braver, 2006), the inferior occipital fasciculus fronto temporal, the vertical occipital bundle that unifies the front upper and lower longitudinal fascicles (Yeatman et al., 2014). The efferencies of the prefrontal nodes to the rest of the central nervous system represent 'hubs'. The complexity of the prefrontal connectivity moved to the architecture of the computer metaphor, liquefying some rigid and ambiguous models.

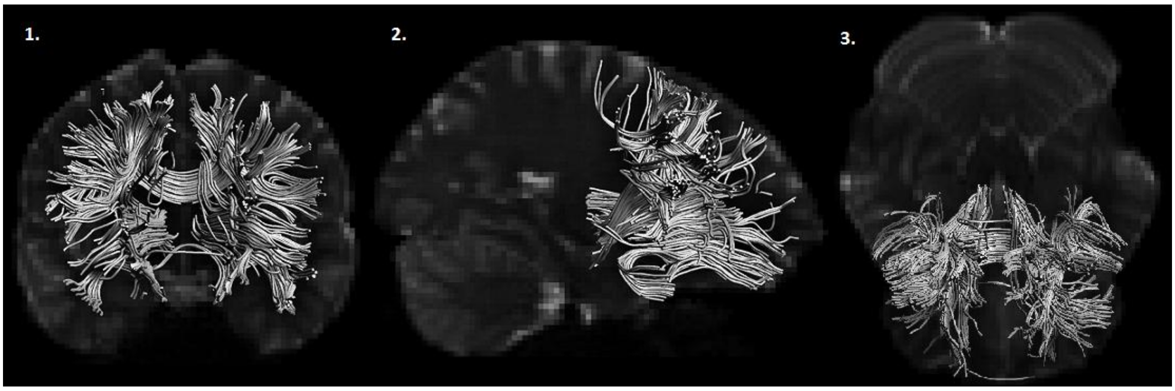


**Figure2.** *Massiveness of the prefrontal connectivity, obtained by diffusion tensor imaging in MRI. Image 1 shows white matter fibbers in coronal slice, Image 2 in sagittal slice, Image 3 in axial slice.*

Each VM is activated improving performance of VMs that control (Q) and transcendcognitive abilities. The crucial question is to clarify the role of emotion and motivation, reward and 'hedonic landscape' of each subject in relation to EFs. Evidence about EFs impairments in depressive disorders, schizophrenia, melancholy, emotional regulation (Aldao, Nolen-Hoeksema, & Schweizer, 2010) is profuse and solid. Thus, the idea of EFs like a super-entity, responds to this quote extrapolated from a macroeconomic context: 'transnational corporations form a giant bow-tie structure and controlled by a large portion of flows to a small tightly-knit core of financial institutions. This core can be seen as an economic 'super-entity'' (Vitali, Glattfelder, & Battiston, 2011). This same vision of economic relations, crystallized on long-range networks is well represented as VMs, sometimes invisible, which are activated and expand the workspace allowinggreater quality to the information which computes the brain- mind system. From the basics of scientific psychology, brain or mind (which are equivalent from the anomalous monism) (Davidson, 1994) have a tendency to turn off the most expensive functions and try to work towards the least difficult way. Glucose consumption in the prefrontal regions results aversive for brain function, whereas automatic default activity is more comfortable. Executive functioning is turned on only when there is a demand alerting thatexceeds automated storage ability to solve problems or adjust. Brain anatomy accompanies this idea, since cerebral vasculature presents the Willis polygon and basilar anterior and posterior arteries associated with midbrain and nearby areas, while the prefrontal cortex is one of the most remote and innervated zones. This demands a greater expansion in the neurovascular braked (branches?), which is related to the evolutionary conceptions of cerebral blood flow (Andrews, Bharwani, Lee, Fox, & Thomson, 2015). Once an executive VM is turned on, people can activate transcendent parallel computations. Care processes become more efficient, increasing cognitive flexibility, and improving both the space to store memory traces and cognitive flexibility.

The metaphor of the activation of VMs implies a reversal of the dominant conception of the volition-controlled EFs. The stronginvolvement of the cerebellum in the activation of EFs has been demonstrated in several studies (Schmahmann, 2004; Thach, 1996). Thus, it has been linked to processes such as emotions, language, working memory, planning, decision making and mental flexibility (Cooper et al., 2012; Koziol, 2014; Riva & Giorgi, 2000). Has been proposed that the cerebellum may play a role in modulating the thoughts and waiting and predicting events, improving the speed and accuracy of cognitive-behavioral responses (Koziol, Budding, & Chidekel, 2012). This suggests that it might be part of the neuronal network serving the Central Executive System (Cooper et al., 2012), within the executive inherited model memory line Baddeley, Allen, & Hitch(2011). These investigations reveal that while the prefrontal cortex could activate FEs without the help of the cerebellum, with the intervention of the latter would in a more automated, quickly and accurately, making comparisons outside of consciousness (controlled processes) contextual information learned mechanisms (Koziol, 2014; Thach, 1996, 2007). From the VMs perspective, this is reflected in the idea that activation thereof during troubleshooting or goal-directed tasks, cerebellar greater participation involves increasing complexity, increased flexibility and process automation, whereby people who are trained in the activation of VMs perform increasingly less effort for highly complex tasks.

Within this concept of EFs as VMs, the following predictions emerge. The EFs have a close relationship with social demands and context. The EFs are also closely related to temperament. Between social demands, context and temperament VMs of EFs require complex multivariate models to be measured, including multi-stratum nested statistics models. EFs would be associated with activation of a 'machine language' that allows better handling than manipulating a lightweight and flexible software. In other words, EFs have enabled workspaces that amplify the power for prediction and learning processes via the detection of key generation strategies. How could they do it? By empowering shifting, cognitive flexibility and inhibition resources.The same happens in memory tests, when people motivation rates decreaseand they do not generate chunking strategies over digits or words, while people highly motivated reach strategies that enhanced their performances via activation of VMs. The novelty of the metaphor of EFs as virtual machines, is that the strategies are easily detected in -for example - memory capacities, but, considering the allowing effort to amplify the mindspace work by activation of VMs that contains the classical EFs powerful mechanisms to make the computation(?). Signals from this space generate executive mnemonic strategies stable operations.

A crucial issue of this conjecture will now enter in turbulent air, because it involves a reversal of the traditional conception of the EFsrelationship with the controlled and automatic processes of the mind. Does the activation of VMs of EFs represent an activation of powerful automatic control mechanisms disposed to ensure the best form of learning and prediction? Contrary to current ideas of EFs as controlled or conscious processes, VMs generate working and interconnected spaces in a stratum design. It would lead to better learn and use more smoothly and free interchangeably course of computations free of the repetitive influence of long time stored information. Instead, the cognitive capacities such as memory subsystems, attention or sensory abilities would have greater ability to be controlled. This theoretical investment gives greater weight to concentration, contextual control, learning, emotions, personality, temperament, education and culture variables facing EFs. This represents a significant change to the metaphorical conception of Lezak (2004): EFs depends largely on contextual stimulation and even cultural control of individuals via goals generation. It began on the idea that the brain-mind system essentially aims predicting anticipation of possible aversive consequences, avoidance of energy expenditure. It highlightsthe importance of motivation for entering each person in the 'painful' world problem solving which requires more planning of trials combined errors than people consciously think. From the metaphor of EFs as VMs that are activated, engaged in problem solving and goal-directed tasks it involves an increasing complexity. However, activation of VMs makes the increasing complexity a stratrum nonlinear processaccompanied by higher crosslinks (flexibility) and the person trained in the activation of VMs takes less effort to make highly complex task because the VMs machine language attached to temperament, inhibition and emotions coping progressively faced with high difficult tasks. Thus, what is called intelligence could be replaced by concentration, effort and its connection with the 'hard' EFs activated by VMs.Also, strategies will be nested to be reinserted into the domain of creating subdomains strategies in basic skills.

## CONCLUSIONS

The metaphor of the EFs as activation of VMs needs an empirical support. It is a line of thought that would offer predictions, avoiding multiplication of entities without necessity (Scheibehenne, Rieskamp, & Wagenmakers, 2013). It would be aligned with the call of Barrett (2010) for a new language for psychology with better concepts to overcome the legacies of the concepts of the soul philosophy (Marino &Luna, 2013). Virtual machines are even related to psychological concepts from other fields such as Flow of Csikszentmihalyi (2014). The mental activity described by 'flow' would perform complex activities with use parallel computing of VMs. Flow would be a son of Effortful Control, and EFs a possibility to better treat information in simultaneous labs. The VMs, which meets the demand of importance in solving problems, avoid the punishment of unproductive 'mind wandering' and are the operators that concentration allows for multiple parallel higher connectivity computations. To activate the executive VMs a series of 'pain' to overcome obstacles 'pleasure principle' (Freud, 2001) would be necessary. Then, the properties of the EFs are clear, were defined and can be refined as did the group of Akira Miyake (Miyake et al., 2000). However, if they are an expansive possibility of automatic processes acquired by explicit and implicitlearning needs to be 'empiricized'(?). There is a need to distinguish between what is a cultural demand (adaptation, to be self-sufficient), a psychological process (conflict resolution), to improve basic capacities (greater memory storage) and processes related to personality traits (decision making).

Finally, we propose three main reasons to think EFs as VMs:

- VMs are operating systems that can be added to an existing one, but also you can dispense: the fact thatEFs have a relevant cultural baggage indicates that they are something that can only emerge in particular contexts. Evidently, we have a neuronal structure compatible with ‘the installation of new software’ but until they are learned or ‘installed’, each person can only run programs ‘by default’, like the basic psychological processes. The farmers in Tatarstan could be an example of cultures without EFs, although biologically they have no significant structural differences from a businessman.
- VMs, even if they are installed, are programs that do not normally run until they are initiated or activated: Something similar occurs withEFs. Motivation, effortful control and learning can be put them into operation, and are activated to solve complex tasks which demand is rare, compared with other brain processes ‘by default’.
- VMs are systems that add or improve the functions that can run in a ‘native’ operating system: similarly, EFs improve the workspace and/or provide new mechanisms to enhance, coordinate and make more efficient the simple cognitive processes.

## ACKNOWLEDGMENTS

This article was inspired in our formal and informal communications with Dr. Juan Lupiáñez, from the Cognitive Neuroscience Group of the University of Granada. However, this does not imply that he agrees with all the concepts here exposed.

## REFERENCES

[1] Aldao, A., Nolen-Hoeksema, S., & Schweizer, S. (2010). Emotion-regulation strategies across psychopathology: A meta-analytic review. Clinical Psychology Review, 30(2), 217–37. doi:10.1016/j.cpr.2009.11.004

[2] Baddeley, A. D., Allen, R. J., & Hitch, G. J. (2011). Binding in visual working memory: The role of the episodic buffer. Neuropsychologia, 49(6), 1393–1400.

[3] Barrett, L. F. (2009). The future of psychology: Connecting mind to brain. Perspectives on Psychological Science, 4(4), 326–339.

[4] Barrett, L. F., Lindquist, K. A., & Gendron, M. (2007). Language as context for the perception of emotion. Trends in Cognitive Sciences, 11(8), 327–332. Doi: http:// dx.doi.org/ 10.1016/ j.tics. 2007.06.003

[5] Botvinick, M. M. (2008). Hierarchical models of behavior and prefrontal function. Trends in Cognitive Sciences, 12(5), 201–8. doi:10.1016/j.tics.2008.02.009

[6] Catani, M., & Thiebaut de Schotten, M. (2008). A diffusion tensor imaging tractography atlas for virtual in vivo dissections. Cortex, 44(8), 1105–1132.

[7] Cooper, F. E., Grube, M., Von Kriegstein, K., Kumar, S., English, P., Kelly, T. P., … Griffiths, T. D. (2012). Distinct critical cerebellar subregions for components of verbal working memory. Neuropsychologia, 50(1), 189–97. doi:10.1016/j.neuropsychologia.2011.11.017

[8] Kalisch, R. (2009). The functional neuroanatomy of reappraisal: Time matters. Neuroscience & Biobehavioral Reviews, 33(8), 1215–1226.

[9] Koechlin, E., & Summerfield, C. (2007). An information theoretical approach to prefrontal executive function. Trends in Cognitive Sciences, 11(6), 229–235.

[10] Koziol, L. F. (2014). The Myth of Executive Functioning. Cham: Springer International Publishing. doi:10.1007/978-3-319-04477-4

[11] Koziol, L. F., Budding, D. E., & Chidekel, D. (2012). From movement to thought: executive function, embodied cognition, and the cerebellum. Cerebellum (London, England), 11(2), 505–25. doi:10.1007/s12311-011-0321-y

[12] Leemans, A., Jeurissen, B., Sijbers, J., & Jones, D. K. (2009). ExploreDTI: A Graphical Toolbox for Processing, Analyzing, and Visualizing Diffusion MR Data. In 17th Annual Meeting of Intl Soc Mag Reson Med (p. 3537). Hawaii, USA.

[13] Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. Cognitive Psychology, 41(1), 49–100. doi:10.1006/cogp.1999.0734

[14] Newell, A., & Simon, H. A. (1972). Human problem solving (Vol. 104). Prentice-Hall Englewood Cliffs, NJ.

[15] Poldrack, R. a. (2006). Can cognitive processes be inferred from neuroimaging data? Trends in Cognitive Sciences, 10(2), 59–63. doi:10.1016/j.tics.2005.12.004

[16] Riva, D., & Giorgi, C. (2000). The cerebellum contributes to higher functions during development: evidence from a series of children surgically treated for posterior fossa tumours. Brain: A Journal of Neurology, 123 (Pt 5, 1051–61.

[17] Schmahmann, J. D. (2004). Disorders of the Cerebellum: Ataxia, Dysmetria of Thought, and the Cerebellar Cognitive Affective Syndrome. Journal of Neuropsychiatry, 16(3), 367–378. doi:10.1176/appi.neuropsych.16.3.367

[18] Shackman, A. J., Salomons, T. V, Slagter, H. A., Fox, A. S., Winter, J. J., & Davidson, R. J. (2011). The integration of negative affect, pain and cognitive control in the cingulate cortex. Nature Reviews Neuroscience, 12(3), 154–167.

[19] Thach, W. T. (1996). On the specific role of the cerebellum in motor learning and cognition: Clues from PET activation and lesion studies in man. Behavioral and Brain Sciences, 19(03), 411–433. doi:10.1017/S0140525X00081504

[20] Thach, W. T. (2007). On the mechanism of cerebellar contributions to cognition. Cerebellum (London, England), 6(3), 163–7. doi:10.1080/14734220701373530

[21] Thiebaut de Schotten, M., Dell'Acqua, F., Forkel, S. J., Simmons, A., Vergani, F., Murphy, D. G. M., & Catani, M. (2011). A lateralized brain network for visuospatial attention. Nature Neuroscience, 14(10), 1245–6. doi:10.1038/nn.2905

[22] Vega Rodríguez, M. de. (1984). Introducción a la psicología cognitiva. Alianza Editorial.

[23] Von Der Heide, R. J., Skipper, L. M., Klobusicky, E., & Olson, I. R. (2013). Dissecting the uncinate fasciculus: disorders, controversies and a hypothesis. Brain: A Journal of Neurology, 136(6), 1692–1707. doi:10.1093/brain/awt094

[24] Yue, Y. R., Lindquist, M. A., & Loh, J. M. (2012). Meta-analysis of functional neuroimaging data using Bayesian nonparametric binary regression. The Annals of Applied Statistics, 6(2), 697–718.


## AUTHOR'S BIOGRAPHY

**Julian Marino** is a neuroscientist from the Argentinean Patagonia. I FORMED I was at the National University of Cordoba (Argentina) where received His PhD. Interested in Neuroimaging (Magnetic Resonance Imaging) applied to mentally Brain-embodied process, Continues His postdoctoral studies in Europe, mainly at the University of Granada (UGR), Spain; receiving support from different sponsors and finnancement government of Spain and UGR neuroscience group. At now, I is leading the Neuroimaging Laboratory at the National University of Cordoba, Including Formal and strong bindings with Research groups from Spain, Sweden, Poland, Italy, Mexico, Japan and the Netherlands. Interested in a new language for psychological process which leaves behind the traditional medieval heritage soul- body concepts, the author arrived to the work of Lisa Feldman Barrett's work acerca psychological primitives, with confidence. That neuroimaging studies will process through effective light for a new language in Neuropsychology. Main fields of research: Diffusion Tensor Imaging (Magnetic Resonance), Mathematics Models in Psychology, Semantic Executive Control, Psychological Task Programming.