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Towards a unified approach to sciences and the arts

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ABSTRACT

The process of 'comprehending how we comprehend', requires elucidating fundamental cognitive mechanisms used by the brain. In these regards, this article discusses two basic hypotheses. First, *unconscious and conscious processes form a continuum*. Second, *humans have a predisposition to construct real versions of mental images and of unconscious structures, as well as to assign to them specific symbols*. In addition, it is claimed that our process of comprehending is aided by invoking certain concepts which are important because, apparently, they reflect fundamental cognitive mechanisms. Among them are the notions of *continuity*, *associations*, *abstraction, reduction*, *unification*, and *generalization*, as well as the dialectic pairs of *local versus global* processes and *simplicity versus complexity*.

Introduction

How and when do we become aware of an object? Which are the mental advantages of humans in comparison to our evolutionary predecessors? Can mathematics have in biology the transformative impact it has had on physics? Why can we comprehend aspects of the universe? What is the origin of the emotional responses evoked by paintings of Piet Mondrian and Kazimir Malevich?

In order to address these and myriad other important questions it is necessary to elucidate fundamental mechanisms used by the brain. In this connection, this article discusses two basic hypotheses, introduced by Fokas (2024). First, *unconscious and conscious processes form* a dynamic *continuum*. This implies that every conscious experience is preceded by un unconscious process. Although many neuroscientists have appreciated the primacy of unconscious processes, it does not appear that this hypothesis has been stated clearly before. Also, importantly, several distinguished scholars have claimed that conscious awareness is a discrete, all-or-nothing process. This is inconsistent with the above hypothesis which implies that consciousness is a gradual, continuous process. A very recent study provides direct support of the first hypothesis (Cohen *et al*., 2023).

The second hypothesis states that *humans have the unique cognitive advantage,* in comparison to our evolutionary predecessors*, that they possess a predisposition to construct real versions of mental images and of unconscious structures, as well as to assign to them specific symbols*. In addition, it is emphasized here that our process of comprehending is aided by invoking the fundamental concepts stated in the abstract.

It appears that a framework based on the above hypotheses and concepts, makes it possible to approach basic questions, like those posed at the beginning of this introduction, in a unified, interdisciplinary manner, opening the way for a deeper contemplation.

It is worth noting that the existence of a direct relationship between consciousness and the activation of specific neural circuits was proven in the pioneering experiments of Adrian Owen (2006) in Cambridge who, using Functional Magnetic Resonance Imaging, was able to communicate with patients thought to be in the vegetative state. These remarkable results are reviewed in Chapter 15 of Fokas (2024).

The importance of unconscious processes is illustrated by discussing the process of visual perception in the following sec-

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Contributions: unconscious processes and consciousness form a dynamic continuum; metarepresenations provide the unique characteristic of humans.

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tion. This also illustrates the concepts of continuity, associations, and the pair of local *versus* global interactions. The time scales involved in the passage from unconscious processes to conscious experiences are discussed in the section *The problem of 'free will'*, where also the problem of 'free will' is placed within the proper framework of the unconscious-conscious continuum. The novel concept of metarepresentations, which it is claimed that it provides the key cognitive advantage of humans, is discussed in the penultimate section. Finally, in the last section it is noted that painting of Mondrian and Malevich provide a beautiful example of the concept of reduction, whereas our ability to understand aspects of the universe illustrates the dialectic interplay of local versus global processes and simplicity *versus* complexity.

Visual perception and the importance of unconscious processes

Regarding the first question posed in the introduction it is noted that visual perception is achieved via the process of *deconstruction* and *reconstruction*. In particular, for the recognition of a specific object, the brain's input is the distribution of photons emitted from this object. As soon as the photons arrive at the retina, a complicated neural process is initiated, which finally gives rise to the creation of the *mental image* of the object[1]. This is the reason why Gerald Edelman (Nobel Prize in Medicine 1972) writes: "Every act of perception is an act of creation" (Edelman and Tononi, 2008). Perhaps a more accurate statement is, 'reconstruction is achieved *via* the solution of an inverse problem'. An inverse problem is defined as follows: determine an entity from the knowledge of some indirect data associated with this entity. For example, in Computerised Tomography, the image, say, of lungs is constructed from the knowledge of the so called sinogram, which is specific data obtained from the scanner. A useful paradigm for appreciating the suggestion that reconstruction involves the solution of an inverse problem is provided by the reconstruction of the object shown in the left top Figure 1, using Single Photon Emission Computed Tomography (SPECT) (Figure1).

In order to use SPECT to reconstruct the two-dimensional image shown in the top right of the figure, a specific radiotracer is placed in the holes of the three-dimensional object shown in the top left of the figure. Because of radioactive decay, this radiotracer emits photons, which are captured by the detectors. The SPECT scanner collects these photons and stores their distribution in the form of the so-called sinogram, shown in the bottom left of the Figure. The *inverse problem* for SPECT involves the reconstruction of the image of an object from the knowledge of its corresponding sinogram. The use of a complicated mathematical formula (Protonotarios *et al*., 2018) yields the two-dimensional image shown in the bottom right of the Figure.

In visual perception, the external input used by the brain is also the distribution of the photons emitted by a given object. However, in contrast to the mathematical algorithm used in SPECT, the brain, in addition to utilizing the knowledge of the precise distribution of the emitted photons, it also uses prior information stored in appropriate neural circuits. This information, which is employed in a highly dynamic manner, has been created via earlier interactions with external or internal stimuli and has been stabilised via intricate processes involving memory.

A person who becomes aware of a given external percept is completely unaware of the complicated *neural 'computation's* responsible for the reconstruction of the *mental image* of this percept; these computations are unconscious.

In summary, visual perception involves the process of deconstruction and the solution of a complicated inverse problem. The latter solution is achieved via unconscious neural computations. Thus, in visual perception, awareness is preceded by an unconscious process. Actually, the first hypothesis states that this sequence is a fundamental feature of *all* mental processes.

The existence of an unconscious process is a necessary but not a sufficient requirement for the generation of a conscious experience. Indeed, only a very small subset of unconscious processes leads to awareness. In visual perception, if a stimulus is too weak or too brief or too noisy, then it is *subliminal*; namely, it will be perceived by the brain, but it will not give rise to awareness. By employing functional Magnetic Resonance Imaging (fMRI), it is shown in (Dahaene, 2014) that a written word presented on a computer screen for only 32 milliseconds under masked conditions is perceived by the brain, but it is not seen consciously; in this case, fMRI shows a localised brain activation. The same word presented for a longer period becomes visible, and then fMRI suggests a widely distributed brain activation.

In visual perception the *constituents* of a given percept are reconstructed in separate parts of the brain *via* the solution of *local* inverse problems. Indeed, in early unconscious visual processing, the involvement of short *local* loops is of vital importance for piecing together multiple fragments of a scene (Sporns *et al*., 1991). In particular, the solutions of such inverse problems reconstruct the orientation, colour, and motion of a given per-

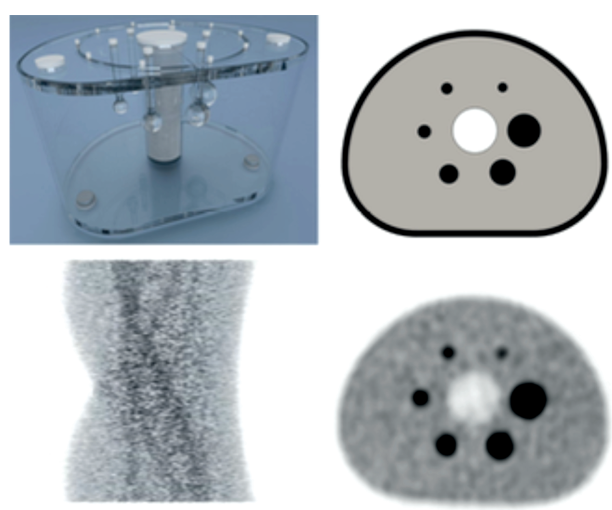

Figure 1. The National Electrical Manufacturers Association (NEMA) IEC Body phantom used for simulation of whole-body imaging especially using positron emission tomographs (PET) and camera-based coincidence imaging techniques Reprinted from SuperTech, retrieved December 9, 2021, from https://supertechx-ray.com/QualityControlPhantoms/pro-project-pro-nm-nema-nu2.php

[1] The existence of photons was established by Albert Einstein (Grundlagen der allgemeinen Relativitätstheorie. Ann Phys 1916;49:769-822). Details can be found in Chapter 13 of Fokas (2024).

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cept. This involves neural computations of specific *local neural circuits* that are located in specific parts of the brain. The solution of each of these inverse problems gives rise to the unconscious reconstruction of specific ingredients of the percept. If there exists sufficient amount of incoming energy entering the retina, then there will occur the simultaneous excitation of several of the local neural circuits *associated* with aspects of this percept, giving rise to *global* activation. The synchronous activation of these interconnected local neural circuits results in the integration of the solutions of the local inverse problems, and this yields awareness, taking the form of a *mental image*.

The above interaction between *local and global processes* is intimately related to the brain's *modular specialization*, namely, with the existence of specific regions of the brain which perform specific tasks. This modularity is facilitated by the existence of highly specialized neurons. The Spanish neuroscientist and pathologist Santiago Ramon y Cajal (Nobel Prize in Medicine 1906), in addition to discovering the *neuron*, i.e., the elementary unit of the nervous system, also discovered that cortical neurons are organised in cellular columns. David Hubel and Torsen Wiesel (Nobel Prize in Medicine 1981), were the first to establish the *functional* importance of such organisation. In their classical experiments with cats, they showed that cells that are excited by the same orientation are organised in a single column. By employing two-photon imaging and large-scale electron microscopy, the neural anatomy and function of specific stimulus-orientation neural networks in mouse's primary visual cortex has been delineated (Bock *et al*., 2011). The orientation of neighbouring cells in a column differs by only a few degrees, and the combination of all these cells form a column that covers all possible orientations, *i.e.* 180 degrees. Furthermore, there exists a column for the left eye and one for the right eye. By combining these two columns into a *hyper-column*, which consists of a one-millimetre strip of neuronal tissue in the area of the brain called V_1, it is possible to detect any line with any orientation at any position in the visual field. It was later discovered (Livingstone and Hubel 1984) that hyper-columns have more structure: in the area called V_4, there exist hyper-columns that contain *blobs*, namely cells sensitive to colour. Furthermore, in the area called V_5, there exist hyper-columns containing cells that respond to movement. In addition, it has been shown that at each successive stage in visual processing, neurons become selective for more precise features, such as corners, curvature, *etc*. Neurons in the visual area V_1 make mostly *local* connections, communicating primarily with their neighbouring areas: V_1 is primarily connected to V_2, which in turn is primarily connected to V_3, and so on. In contrast to this local connectivity, the cortical layers II and III house large pyramidal cells which are ideally suited for the *global* activation required for the emergence of consciousness. Thus, the anatomical brain connectivity provides the basis for the optimal integration of the brain's modular functional specialization facilitating the emergence of consciousness. Incidentally, the process of integration can occur spontaneously without external input, as happens for example in dreaming and imagining.

Interestingly, the extensive activation in visual perception associated with consciousness gives rise to waves that are *bidirectional*: information travels back and forth from the primary visual cortex to other structures involved in vision, including the *thalamus*. Actually, there are many more connections from the thalamus to the primary visual cortex than the other way around. This suggests that the process of integrating the information provided by the local neural circuits involves a highly dynamic process employing guesses, inferences, and iterations. In particular, in the case of a *known* percept, this procedure finally converges to a perfect 'fit', namely, the integrated solution is achieved via the activation of an *existing* neural network.

The problem of 'free will'

The above summary of key neuronal mechanisms involved in visual perception raise various questions, including the following: how does the brain 'know' which local neural circuits should be integrated? Also, what is the time scale of the transition from unconscious perception to awareness? The detailed delineation of neuronal mechanisms pertinent to the first question remains open. However, it is known that the process of *associating* different entities with a given percept is facilitated by learning. In this process, most of the relevant *associations* remain unconscious. Regarding the second question, although the corresponding time depends on the particular mental function involved, in general, the transition from the unconscious to awareness is rather slow. This is not surprising, since the high complexity of the relevant inverse problems demands sufficient time for their solution.

For example, if a word is flashed on a screen, EEG measurements show that an activation, which takes the form of a positive wave, occurs in the primary visual area after 100 milliseconds. This is followed by a negative wave peaking at 170 milliseconds. These waves appear independently of whether the word is subliminal, or it will become conscious. In the latter case, there is a substantial increase in the brain's activation, especially in frequencies of 25-100 Hz, which starts around 300 milliseconds and takes the form of a massive positive wave. This activation can be recorded by distant electrodes, which means that it occurs in an extended part of the brain.

The time duration of approximately a third of a second noted above, is apparently also valid for other sensory activations. For example, Benjamin Libet in experiments performed in the late 1950s (Libet, 2005) showed that a stimulus consisting of a single pulse of current of very weak strength and of duration 0.1 to 0.5 millisecond applied to the skin, creates a signal that reaches the sensory cerebral cortex after 14-50 milliseconds from the time of the skin stimulation. The precise time interval depends on the distance between the brain and the point of skin stimulation. For a short path, such as a path originating in the head, the time needed is 14-20 milliseconds, whereas for a longer path, such as a path from the foot, the time needed is 40-50 milliseconds. In the sensory cerebral cortex, the signal gives rise to a cortical activation expressed as an electric potential that is known as 'evoked potential'. This activation lasts for about 125 milliseconds; at this moment there does not exist sensory awareness. The primary evoked potential is accompanied by a sequence of additional potentials of duration of approximately 350 milliseconds, called 'event-related-potentials'. The primary evoked potential is exhibited only in a highly *localized* small area of the primary sensory cortex, whereas the later event-related-potentials are *broadly distributed* in the cortex. Awareness takes place only after the appearance of these additional potentials. This extended activation reflects 'neuronal calculations' by several local neural circuits associated with additional features of the sensation of touch. The global integration of these local activations yields the mental image of the specific touch experience. Under general anaesthesia, the primary evoked potential remains intact and it may even be enlarged, but the later event-related-potentials disappear.

Libet (2005) also established that time-lag in awareness occurs for events where the stimulus is endogenous, as for example, 'the decision to act'. In this case, this pioneer neuroscientist in addition to finding, as expected, that subjects became aware of 'wanting' to carry out a specific act approximately 150 milliseconds before the execution of this act, he also found that there was brain activation approximately 400 milliseconds *before* the subjects became aware of their decision to act. This finding has generated a lot of interest beyond neuroscience, with some distinguished philosophers considering this work as evidence for the non-existence of free will. If this finding is analysed within the hypothesis postulated here that unconscious and conscious processes form a continuum, then Libet's famous result becomes predictable. Indeed, since every conscious experience is preceded by an unconscious process, the awareness of 'wanting to perform a given act', *must* be preceded by the unconscious decision to act. The readiness potential is the local brain excitation corresponding to this unconscious process. When we become aware of our decision to act, we are simply 'informed by our brain' of what the brain 'has already decided'.

The question regarding the relationship of Libet's experiments and the existence of free will seems to me meaningless: since unconscious and conscious processes form a continuum, it is epistemologically wrong to identify free will only with consciousness, ignoring the crucial role of the unconscious processes. Indeed, our thoughts, feelings, and behaviour are determined by our genes and our prenatal and postnatal learning. These factors do not only shape our consciousness but also determine our unconscious.

Metarepresentations: a uniquely human ability

Hopefully, the above discussion illustrates the paramount importance of unconscious processes. This becomes even clearer by invoking a mechanism absolutely essential for life, namely *homeostasis*. This refers to those processes necessary for maintaining within the interior of an organism several conditions needed for survival and reproduction. Even unicellular organisms possess primitive homeostatic mechanisms as clearly shown during the growth of bacteria in culture, where bacteria migrate towards food by employing appropriate chemical signals. The more advanced the neural system of an organism, the more effective the associated homeostatic mechanisms. For example, the worm *C. elegans* possesses only 302 neurons, but still exhibits 'intelligent' behaviour to maintain homeostasis. For example, these worms feed separately if there is plenty of food in a non-threatening environment, but in the opposite situation, such as in the case of scarcity of food in the presence of an unpleasant odour, they feed in groups (Bargmann, 1996).

Humans achieve homeostasis by employing reflexes and mostly unconscious processes. The crucial role in homeostasis of emotions, which are the unconscious form of feelings, has been elucidated by the leading researcher of emotions-feelings, Antonio Damasio (2018).

It is natural to speculate that at some stage early in the evolutionary tree, the following 'miracle' took place: the brain *informed* the organism that some homeostatic parameter was outside its optimal range. Evolution 'understood' that it would be easier for the organism to correct the departure from homeostasis, if the organism was aware of it. Presumably, the first act of the brain 'informing itself what it already knew', involved pain, thirst, hunger, or temperature. It is reasonable to speculate that this was expressed as a vague feeling of discomfort. This primordial form of awareness constitutes the first instance of consciousness.

The emergence of awareness is perhaps the most advanced tool of nature's armament in its stochastic struggle to create organisms that have an advantage in survival and reproduction. The importance of this invention is demonstrated by its employment in an uncountable number of other circumstances: from mechanisms of 'proprioception' (sense of one's bodily positions) and 'kinaesthesia' (sense of one's movement of bodily parts) to sensory perception, memory, learning, and imagination. In particular, by integrating parts of such a variety of information, *self becomes aware of itself*, and this gives rise to self-consciousness. In this sense, subjectivity and self-consciousness are not prerequisites but consequences of consciousness. This point of view is consistent with Stanislas Dehaene's position: "becoming conscious of aspects of myself, such as my body, my feelings, or my thoughts … is like becoming conscious of say colour" (Dahaene, 2014).

Animals possess effective homeostatic mechanisms as well as consciousness. This raises the important question of why we differ from animals qualitatively as opposed to quantitatively? I believe that the distinguishing characteristic of humans with respect to our evolutionary predecessors is our innate predisposition to *construct real versions* of our mental images and of unconscious structures, as well as to assign to them specific symbols. The outcome of these constructions will be referred to as *metarepresentations*. Hugely important examples are the arts, language, mathematics, computers, and technology.

The existence of metarepresentations reflects important genetic and anatomical differences between humans and our evolutionary ancestors. For example, our pyramidal cortical neurons, especially in the prefrontal part of the brain, possess a far more extensive network of dendritic spines. Pyramidal neurons of the prefrontal region contain approximately 15,000 spines. A dendritic spine is a membranous protrusion that connects at the synapse with a single axon of another neuron. This highly complex network is due to a family of genes that are uniquely muted in humans (Lai *et al*., 2001). This family includes the famous FOXP2 gene (Vernes *et al.,* 2011) that has two mutations specific to the *Homo* lineage. Regarding key anatomical differences in our evolutionary tree, it is noted that the first molecular difference between human and non-human primates tractable to an anatomical difference in the fossil records was identified in 2004. It is a mutation of the gene MYH16, which took place 2.4 million years ago. The inactivation of this gene led to a decrease in jaw-muscle size. Since, altering the size of muscles can produce dramatic changes in the bones to which they attach, this had a considerable impact in the cranial morphology allowing for the size of the brain to increase (Stedman *et al*., 2004). This may be related to the discovery of fire and cooking. Incidentally, the huge impact of the discovery of fire, and in particular its effect on cooking and on the emergence of free time for contemplation, is argued in the excellent book of Wrangham (2009).

More importantly, in the evolution from early mammals to primates, the specific region of the inferior parietal cortex called *inferior parietal lobule* (IPL) became increasing more conspicuous, reaching a disproportionately large size in apes. It became even more pronounced in humans, where its major part split into the *angular gyrus* and the *supra-marginal gyrus*. The IPL, as a

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result of its privileged position located between the occipital, parietal, and temporal lobes, receives information from the sensory modalities of vision, touch, and hearing, respectively. The IPL is crucial for several important metarepresentations, including language. Also, the angular gyrus is vital for exact mathematics and for abstraction. For example, patients with a deficit in this part of the brain do not appreciate simple proverbs; they understand them only literally as opposed to metaphorically. In addition, the supra-marginal gyrus is necessary for dancing, and importantly, for the effective use of tools. In particular, patients with a deficit in this area suffer from *apraxia*, namely inability to carry out a specific act. The metarepresentation of dancing is an important ritual and artistic act, whereas *tools* are the metarepresentations that provide the seeds for the development of technology. The emergence of such anatomical difference together with appropriate cultural interactions, finally gave rise to a number of metarepresentations fundamental for humanity. The effect of culture has been emphasized by Leah Krubitzer (2014), who has argued that the development of complex language and sophisticated use of tools was the result of the "dramatic role of epigenetic mechanisms", crucially affected by "the social and cultural context in which individuals developed, rather than traditional evolutionary mechanisms".

Several scholars have claimed that the distinguishing characteristics of humans are the consequence of language. Although language is of course extremely important, it is only one of several metarepresentations defining human nature. Metarepresentations, like all other important human mental functions, are the result of the interplay of unconscious and conscious processes. In mathematics the dominant role is played by consciousness, whereas in arts the decisive starting step for high level creations apparently belongs to the unconscious. This was clearly understood by Pablo Picasso; in a conversation in 1935 with Christian Zervos he stated: "It would be very interesting to fix photographically, not only the stage of a painting, but also its metamorphosis. Possibly one might catch a glimpse of the road by which the mind moves towards the concretization of its dream". Is there a more eloquent description of the *construction of a real version of unconscious structures* than the phrase 'the concretization of a dream'? Remarkably, Aron Schoenberg, also used the notion of dream to describe his musical creations: "a composer wants *a posteriori* to find the rules that dictate the musical forms that he conceived as in a dream".

Important concepts reflecting brain mechanisms

The appreciation of the fundamental importance of *associations*; the indispensable role of *continuity*; the deep relationships existing between *abstraction, reduction*, *unification*, and *generalization*; and the interplay between *local versus global* processes and *simplicity versus complexity*; are emphasized in Fokas (2024).

As clearly illustrated in the case of visual perception, key mental functions rely on the *global* integration of neural computations performed by *local* neuronal circuits. It is natural to postulate that the *interaction between local and global processes* is *the fundamental feature of all complex phenomena*[2]. For example, in physics, many fundamental laws take the form of *differential equations*, where derivatives express quantities defined *locally*. On the other hand, *solutions* of these equations capture *global* features of the physical reality represented by the underlying laws. The simplicity of the relevant equations versus the complexity of the associated solutions illustrates the dialectic relationship between *local versus global* and *simplicity versus complexity*. Interestingly, this relationship provides an explanation for our ability to comprehend the universe: the local physical laws are simple and hence comprehensible. The solutions of the corresponding equations are global and hence can be exceedingly complicated, capturing the infinitely complex reality.

The holy grail of scientists has always been the *reduction* of any phenomenon to a small set of basic principles. In physics, these principles finally give rise to fundamental laws expressed in a beautiful mathematical form. This explains the miraculous impact of mathematics in elucidating physical phenomena. On the other hand, biological phenomena can be understood within the general framework of biological evolution, whose *modus operandi*, apparently, involves *trial and error*. Namely, new solutions are sought within the constraints of what has already been constructed. Indeed, it seems that evolution tinkers with what already exists instead of creating a completely new system (Marcus, 2009). Assuming that biology indeed differs drastically from physics, the approach of 'mathematical reductionism', which was so spectacularly successful in physics, may not be equally successful in biology. On the other hand, mathematics is the *language of complexity*. Thus, the modelling of any sufficiently complex process benefits from mathematics, and this certainly includes modelling aspects of consciousness.

Reduction is a form of abstraction that is based on an elemental brain mechanism, namely, the *deconstruction of a percept in terms of its building blocks*. Taking into consideration that a mental image is formed via the integration of reconstructions of its ingredients, it is natural to expect that the innate quest for understanding, urges the brain to 'undo' this integration and to attempt to reduce an object or a concept into its constituent parts. This provides a way to understand the paintings of Mondrian and Malevich. The highly cultured neuroscientist and Nobel Laureate Eric Kandel, in his beautiful book *Reductionism in Arts and Brain Sciences* (Kandel, 2016) illustrates reduction in painting by analysing works of Piet Mondrian. As discussed in Fokas and Logothetis (2024, *in preparation*) the works of Kazimir Malevich provide an even better example of the power of reduction. The emotional power of paintings by Mondrian and Malevich is perhaps related with the fact that these masterpieces reveal deep mechanisms used by the brain.

Conclusions

The basic two hypothesis discussed in this paper are summarised in Figure 2, in which the arrow from unconscious structures to mental images indicates that, consistent with the first hypothesis, the former precedes the latter. Both unconscious structures and mental images give rise to symbols, a process that occurs inside the brain. Also, unconscious structures and mental

[2] The pandemic of COVID-19 provides a topical example of this fact: the strategies of mitigation and suppression discussed in Ferguson et al. Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand. London, Imperial College, (2020) are two slightly different approaches of attempting to control the interaction of local versus global.

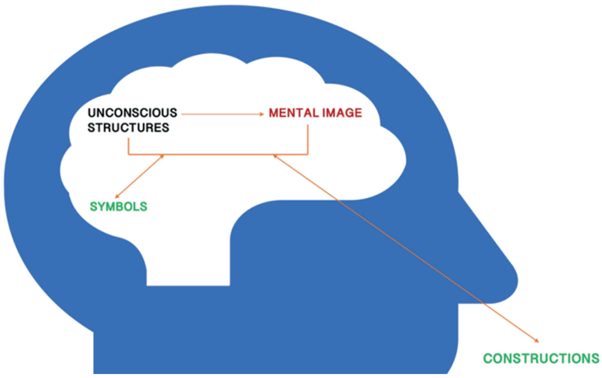

Figure 2. The basic two hypotheses of the paper.

images generate concrete constructions, which take place outside the brain.

The continuous and multilevel interaction between a plethora of metarepresentations and unconscious processes, provides in my opinion, the essence of the astounding human creativity. For example, a mathematician thinking about triangles, is compelled to draw a triangle, which is a concrete mathematical metarepresentation. This figure enhances enormously the possibility of possible new constructions, such as drawing the bisectors, *etc*.

In this article the above processes are illustrated using a variety of interdisciplinary examples. In addition, certain fundamental notions, including the notions of associations, local versus global, and reduction versus unification, are discussed, which appear to provide very useful tools for studying both Sciences and the Arts.

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