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THE LOGIC OF CREATIVITY

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The nature of creativity can be addressed from disciplines as varied as neuroscience, psychology and philosophy. In this brief essay we aim to connect different approaches to creativity, which can help us elucidate some of the fundamental features of the creative process.

1. THE NEURAL BASIS OF CREATIVITY

How should we understand the nature of the creative process? What is the meaning of 'creativity,' broadly understood as the capacity to generate new ideas that show significant degrees of originality with respect to the antecedents from which they depart?

Indeed, creativity is probably the most enigmatic concept of the human mind. For many, its very notion evokes a property that defies any logical explanation. Along this line, in which the exuberant echoes of romanticism still resonate, if creativity could be reduced to a purely rational understanding, to an algorithmic mechanism, to an 'if-then' relation that merely supplements reason, without transcending its scope, it would become deprived of its most intimate essence and it would lose its magic. In this paradigm creativity stands as the explosion of new ideas, detached as evidently as possible from the standard abilities displayed by an average mind, and in this idealized framework it should be enthroned as the greatest gift of humanity and the deepest mystery of science.

Even from a more modest and naturalistic approach, it seems legitimate to distinguish between 'standard creativity,' understood as the general capacity of the human mind to find innovative solutions to old and new problems, and 'genuine creativity.' By definition, genuine creativity must represent a scarce resource that, rather than stemming from successful reactions to emerging challenges, is rooted in a more fundamental and intrinsic motivation, in an impulse to innovate that may perhaps be better described as nested in a certain type of dissatisfaction with the current state of things. But in both cases it is clear that creative approaches are constantly needed for solving intellectual and social problems. Lack of ideas paralyzes scientific progress and social development. Given the impossibility of eradicating any potentially new problem in knowledge and action (because we are continuously confronted by countless contingencies, and in any discovery or innovation we are opening new horizons of possibilities), only a parallel arousal of creative ideas can cope with the new challenges that are insistently emanating from reality. This appearance of new ideas can of course be subject to a process of 'industrialization,' as it happens in many economic sectors, but the question is whether such a mechanism of systematized innovation can be extrapolated to the most fundamental dimensions of human thinking in the sciences and the arts, in which the presence of true paradigm shifts and the role played by genius are often inescapable.

Creativity therefore seems essential for understanding not only the workings of the human mind in its ability to generate new ideas, but also the richness and complexity of social action itself and the historical development of human culture.

From a philosophical point of view some other relevant questions that need to be posed are the following: What are the precise and deepest mechanisms that underlie the unusual creativity displayed by some minds? What kind of explanation do we actually need for modelling this human capacity? How do necessary and sufficient conditions relate when we try to account for the nature of mental creativity? What objects and properties are we trying to understand?

These questions converge on the problem of how to understand the emergence of new ideas that, when assessed from a sufficiently ample historical perspective, seem to generate profound and far-reaching changes within certain disciplines and domains of human action. How do, after all, new ideas arise, and why abundance of knowledge in a certain field does not always lead to true manifestations of creativity?

If we adopt an idealized approach to creativity, inspired by a romantic exaltation of genius, this phenomenon seems to stand as the perpetual resource of imagination, as the encouraging possibility of overcoming any given limit and transcending any potential frame of reference. In its deepest and boldest conception, creativity is thus identified with *creatio ex nihilo*, in which a superior power is capable of producing something entirely new out of nothing. This is certainly the greatest idealization of creativity, because it postulates a radical rupture between the antecedent and the consequent, so as to conceive of the possibility of generating something utterly new. But even if we decide to apply a less ambitious description, which may overcome its theoretical antagonism with reason, any attempted account of creativity seems to challenge the restraints of a definition, as it becomes immediately associated with some sort of supreme freedom, emancipated from the shadows of necessity and capable of outshining the constraints of reason. Hence, in this view creativity emerges as a notion reminiscent of the eternally occult gift of the human spirit.

Thus, in a philosophical reflection on creativity we are gravitating around two dialectical poles: a more *mystical* depiction and a more *rationalistic* account. According to the first perspective, by its very concept creativity defies any explanation susceptible to determining, through principles and rules of inference that organize the available information, the exact outcome of a mental process categorized as 'creative.' In the the second approach, beyond the technical complexities that impede us from explaining all the details behind the emergence of innovative ideas in certain minds, the scientific view of the world is powerful enough as to offer a complete understanding of the fundamental neurobiological and social principles involved in this process. Thus, it should be possible to reproduce the exact, 'microscopic' conceptual itinerary followed by a certain mind before reaching an outcome that may be featured as creative.

Is it then possible to elucidate the neural mechanisms of creativity? In spite of its mysterious character, most expressions of creativity (and perhaps all) do not need to be understood as manifestations of some sort of mystical power. There must be a *via media* between a romantic exaltation of creativity as an inscrutable power that anoints a selected number of chosen spirits and its full reduction to the basic neurobiological processes that rule our brains. Indeed, the best way of expressing our admiration for this blessing of nature in its most genuine meaning is by trying to understand how it works. And it is reasonable to think that one of the most productive sources of human creativity emanates from the association of concepts, forms and contents. Linking apparently unconnected structures -or at least related in tangential terms- may propitiate a cascade of original ideas and enriching perspectives on a specific question, as we shall discuss.

In any case, an important philosophical question should not be avoided in this discussion. For if, in highly simplified terms, a scientific explanation must be capable of understanding the motion of material objects by applying a set of laws on a series of entities, such that a mechanism of action may be unveiled, one can wonder whether a similar approach to the human mind, including the ultimate nature and scope of its cognitive abilities (also creativity), would require the discovery of 'mental laws' that, once applied on mental phenomena, could justify and even predict the action of the mind. Schematically, if in logic we find that Assumptions times Rules of inference to consequences, in the natural sciences this process can be formulated as Objects times Laws equiv motio *n*. Of course, we also need to elucidate rules of formation for those objects. Moreover, in the natural sciences objects can be interpreted as some sort of definitions, and laws can be equated with logical rules of inference (derived from axioms or fundamental laws), which govern the behavior of the system by specifying its transformations from one state to another. In both cases the rules of inference can be contemplated as logical forms expressed through functions, which, by analyzing the syntactic structure of a series of axioms, lead to a conclusion. But just as it seems necessary that a conscious being may study the non-conscious world to become aware of the existence of laws, it could be argued that in order to understand those hypothetical mental laws it would be necessary to rely upon a being endowed with higher faculties than those of standard 'mental beings.'

This objection to the possibility of grasping the nature and activity of the human mind, as if a superior species were needed to unravel these mysteries, is pertinent. However, it seems legitimate to have hope in the power of the human mind itself to stand, rather metaphorically, as a 'law that is not its own law.'[1] Hence, it should not be necessary, at least in principle, to believe that a higher level of legality would be required for understanding the 'laws of the mind,' because philosophically the mind can be defined as that class of reality able to examine, potentially, any object, given its intrinsic openness to different possibilities ('*anima quodammodo omnia,*' a feature most visible under the form of imagination), as the history of scientific inquiry vividly shows.

1.1. Creativity and learning

Within a biological framework, creativity can be regarded as the foremost manifestation of adaptability. Any creature that strives to overcome the challenges posed by mutable environments must display creative behaviors. In the case of human beings, the high degrees of cognitive flexibility propitiated by the parallel processing of information in the brain, through different and often divergent routes, triggers original combinations of elements that unchain new configurations of thought. It is thus a question of properly dealing with the available information, the raw materials on which creative activity is based.

Indeed, evolution has granted the human brain a remarkably wide range of flexibility. The hiatus between the reception of a stimulus and the emission of a response stands as a powerful neurobiological basis of our aesthetic and intellectual creativity. In the words of Joaquín Fuster, 'the liberty to create is a result of the immense plasticity with which evolution has endowed the human brain.'[2] The power of self-reflection originates, to a large extent, from such a relative and growing indeterminacy, which favors an organization as malleable as that of the human brain. For example, I cannot 'come back to myself' if I am obliged to respond immediately to any stimulus stemming from the external world. Thus, I will be unable to exhibit a truly creative behavior if I do not enjoy a certain degree of independence with respect to the world.

Nevertheless, while neuronal processes offer the structural and functional bases of our symbolic life, both history and culture exert unequivocal influence on its development, and the particular genetic endowment, shaped by the influence of the environment, generates a series

of cerebral connections that are specific to each individual: a 'connectome.'[3] The growth of neurobiological knowledge is destined to gradually link the fundamental mechanisms at the neuronal level with the assimilation of subjective experiences and external contents, mediated by cultural factors. Therefore, the study of how the human brain is susceptible to structural and functional modification in accordance with the afferent stimuli may shed light on the nature and scope of creativity.

Furthermore, the future may witness how more powerful technologies become capable of penetrating the 'subjective core' of the human mind; at least, notable advancements anticipate the possibility of an objective study of subjectivity and complex cognitive functions.[4] For example, recent encephalographic research on the production of creative ideas has highlighted the importance of alpha band activation in certain frontal and parietal regions of the right cerebral hemisphere.[5]

In any case, it is by no means trivial to state that the creative products of the mind represent the inexorable fruit of predetermined cerebral processes. Neuroscience offers powerful arguments for including the individual variable in our analysis, especially when we study the most outstanding manifestations of individual creativity. The key concept is that of neuronal plasticity. Indeed, our knowledge of the mechanisms of learning has underscored the important role played by the formation and modification of neuronal connections.[6]

Generally speaking, it can be said that the high degrees of neuronal plasticity shown by the human brain allow us to relativize the burden of inherited neurobiological structures, stored memories and received stimuli. Thus, through a highly flexible representational architecture and a set of powerful algorithms specialized in statistical learning[7] the function may not be necessarily specified by the structure in a unique manner. Thanks to the versatility of these mechanisms of interaction, the subject is capable of establishing a less rigid relationship with the environment and its own neurobiological system. This phenomenon is essentially convergent on the very idea of 'human learning': subjective enrichment through the assimilation of new information, and even with a more parsimonious understanding of learning as the ability to change one's behavior. If we were entirely deprived of the possibility of continuously altering our neuronal connections, our adaptability to a changing environment, from which new and unforeseeable challenges continuously emerge, would be significantly damaged. And without this ability it is impossible to explain the development of sophisticated cultural expressions that are sustained on both the learning (transmitted from generation to generation) and creativity of a certain group.

As early as 1894, Santiago Ramón y Cajal noticed how the relevant experience of the external world affected the configuration of our neuronal connections. In his view, mental exercise elicited a higher degree of development in certain cerebral areas. The previous associations would be strengthened and new intercellular connections would be formed.[8] Today we know that the plasticity of synaptic connections –not only the internal functioning of neural circuits- enjoys a privileged position in learning and processing new experiences.[9] Extrapolating this reasoning to the vast universe of symbols, in which the capacity to gain higher levels of indeterminacy, by combining the existing elements and reformulating the previous contents, is potentially infinite,[10] the most outstanding creations of the human mind can only be elucidated through their insertion in a realm that is overwhelmingly broader and much more complex than the strictly neurobiological sphere.

1.2. Creativity and the unconscious

In a variety of contexts it has been proposed that creativity is often indebted to the power of the unconscious. Thus, the emergence of certain original ideas would be explained not by the act of

focusing the subject's attention on a certain pattern of thought, as it happens in conscious reflection; rather, it would rely upon a repertoire of previous mental operations that remain latent in unconscious processes. This form of creativity would therefore benefit from the parallel work of structures related to the 'conscious brain' and a series of processing routes closely connected with the unconscious domain.[11] Famous examples, like August Kekulé's dream that led him to the discovery of the structure of benzene, seem to validate this inveterate intuition, elaborated in more sophisticated ways by Freud in *The Interpretation of Dreams*. Clearly, on many occasions unconscious activity represents the concealed treatment of knowledge and thoughts that we have consciously and lucidly developed, but which now lie in the depths of tacit memory.

Indeed, it is legitimate to suspect that the mechanisms used by the brain in the course of the creative process resemble those of dreams. The images that appear in our dreams cannot obey pure chance, because they are always supplied with previous experiences, preoccupations, intellectual interests and outstanding impressions that have been stored in our memory. Their raw materials frequently stem from people, concepts and events that have reached us during that day or in the previous days. In any case, the intensity of our experience seems to demand a 'detachment,' the configuration of a new world that deliberately moves away from reality, although it is shaped by actions and events that we have felt for ourselves in the real world.

Phenomenologically, in an intuitive manner it can be said that the very psychological intensity faced by the creator, the irrepressible need to consecrate his mental energies to a problem or an aesthetic challenge, generates thundering tensions. Too much energy is flowing. The electric nets of his intellect are saturated, and creativity flourishes. But this is not a merely fortuitous phenomenon. The creator has already dedicated himself in body and soul to thinking about a particular question. This overcrowding of intuitions is capable of instigating fruitful analogies, fertile associations among the elements involved, praiseworthy spiritual games that do not adhere to pre-established parameters, but dare to glimpse the new. His analytical *finesse* has therefore succeeded in dissecting these categories and experiences until he perceives their foundations, their primordial nuclei, so that a mind blessed with such a synthesis of power, intelligence and sensitivity, with such an admirable degree of assimilative vigor, arrives at the gates of a notion that may be regarded as truly creative. Thus, it is only a question of time, fortune and a small number of stimuli for a true creative ecstasy to be unleashed. Also, one should not forget that this mind has already focused its attention on objects somehow related, which are not absolutely extrinsic or disparate from each other.

While these claims may seem too speculative and empirically unwarranted, from a purely philosophical perspective it is legitimate to state that the mixture of imagination and reality that defines the nature of dreams mitigates a tension too sharp between the potential richness of our inner world and the uncontrollable sensations that emanate from ordinary life. The dream reconciles these two tempestuous oceans by creating a new scenario, where imagination can operate freely. Perhaps the creative mind is subject to such a high number of 'tensions' and worries, of pressures to think, that, possessing an excess of intelligence, it focuses on a concrete theme, and this anguish is only relieved by a 'disconnection,' as if the fruit were ripe to fall. This occasional discharge, this happy irruption of the new, suddenly links separate provinces of thought. Thus, a promised land rises before his eyes. Of course, this unconscious management of information may not respond to a strict Freudian paradigm, in which the unconscious element plays a very specific and theoretically demanding role, but simply to some sort of subliminal processing, understood in neuroscientific terms as 'a condition of information inaccessibility where bottom-up activation is insufficient to trigger a large-scale reverberating state in a global network of neurons with long range axons.'[12]

Furthermore, it is reasonable to think that the larger the number of routes and the combinations of cognitive and experiential contents, the greater the likelihood of innovative ideas. Against conscious control, predisposed to selecting 'rationally' and 'deliberately' certain pieces of information that are judged as valuable, 'unconscious' routes contribute to providing larger doses of uncertainty and random integration of elements. The combination of sequential and parallel processing seems in fact to be a general feature of the mind. Indeed, it is possible to identify a 'functional logic'[13] that guides the operations of the cortex. The visual system provides the best example of how specialized processing lines working in parallel nonetheless coexist with the capacity of integrating the different outcomes into a unified percept. The exact ways in which this interplay between separation and unification happens is perhaps one of the deepest neuroscientific mysteries. In Karl Lashley's words, 'how [is it that] the specialized areas of the cerebral cortex interact to produce the integration evident in thought and behavior.'[14]

1.3. Creativity and memory

The study of divergent forms of thinking has shown that genuinely innovative processes are not completely divorced from the evocation of ideas stored in memory, at least in their initial stages. 'Construction' and 'reconstruction' are thus outlined not only as complementary strategies but as essential elements for unleashing the emergence of a truly creative phenomenon within human intelligence.

From a phenomenological perspective there is an interesting link between memory and creativity. Memory stores information and retains intuitions. It offers the possibility of maintaining a continuous flow of thought that 'sustains' the strenuous search for a response to a question or a creative approach to a certain field. It then promotes the temporary integration of data and the ability to focus on a particular object or problem. These cognitive skills are essential for fostering creative behaviors. However, the way and the extent to which each of them intervenes have a significant influence on the outcome of the overall process. Storing too much memory – having an arsenal of details on a particular topic- may close the windows of our imagination and saturate us with an excess of content. This fatality may prevent us from thinking in an original and courageous manner. A limited but profound knowledge, which is not overwhelmed by an excess of details but remains focused on 'the core' (and we know how difficult it is to define this 'core'), is more susceptible to being reconciled with information coming from other provinces of knowledge and experience. Therefore, the challenge is to find an optimal point between creativity and knowledge, or between originality and technique, in any domain of human activity.

Indeed, a similar tension between 'expansion' and 'contraction' is faced by any complex being endowed with a high capacity for processing data, given that this ability may succumb to information overload, a risk whose solution demands the application of selective mechanisms. Common sense urges us to think that a very fine and deterministic 'Laplacian' type of intelligence, kidnapped by the meticulous analysis of all the details and obsessed with the elucidation of all possible options, becomes obscured and alienated from creative imagination. Creativity nests in the ability to inhibit certain stimuli, in order to focus attention on a particular angle that ultimately inaugurates a new scenario. Superabundance of information and stimuli, the *ad extra* increment of knowledge, is of little use if it is not accompanied by an *ad intra* growth: greater depth in the contemplation of concepts (a Pascalian *esprit de finesse*). To think is to associate, but there would be no thinking without selection and inhibition of stimuli and certain lines of reflection. Thus, the best form of thinking seems to emerge from an optimal combination of association and selection.

Furthermore, it is important to take into account that the emotional and cognitive systems seem to be integrated in the dorsolateral prefrontal cortex of the brain[15] (and certainly, without

the expansion of the associative areas of the cortex it is impossible to understand the astonishing increase of the intellectual abilities that have led to the genesis of the human mind). In this way, the old intuition that creativity does not depend solely on intelligence, but also on a special form of sensitivity, on the capacity to be moved by the surrounding environment, so as to aspire to generate something new, can now be translated into neuroscientific language. Indeed, some of these empirical and phenomenological results help to emphasize the importance of considering different kinds of creativity in accordance with their emotional or cognitive character.

2. THE POWER AND LIMITS OF ANALOGICAL THINKING

The association of that which is different through a shared element (a kind of 'least common denominator') converges into the philosophical concept of 'analogy.' In every analogy there are at least three fundamental elements: the two terms under analysis and the common structure (property, content, form ...) that they may share. An analogy postulates a relation, an expression of proportionality, of correspondence between the properties of the first term and those of the second. This connection is suggested on the grounds that both terms show a series of convergent features, which approach them suspiciously, even if each object has its own semantic field and conceptual domain.[16]

The nature and classes of analogy were widely studied by the scholastics in the Middle Ages, frequently motivated by theological interests, such as the elucidation of the senses of the Holy Scriptures and the relationship between the human and divine natures in the person of the Incarnate Word; although in other cases the influence exerted by the logical treatises attributed to Aristotle also planted the seed of the interest in the topic.[17] More recently, some authors have tried to extend the concept of analogy to encompass a more ambitious model of human thinking, which essentially gravitates around the conversion of dormant long-term memories into active short-term memories.[18]

Indeed, it is interesting to notice that the Stagirite was a pioneer in promoting a rationalistic understanding of creativity. His approach seems rather distant from a more romantic approach to the subject, in which the temptation to interpret creativity as an undomesticated gift from the gods, as an updated version of celestial grace, whose power raises a few chosen ones above the standard limitations of human nature and the deterministic condition of many of the forces that shape our subjectivity, is certainly pressing. For according to Aristotle the appropriate use of metaphors and analogies is essential for characterizing genius. Thus, in his framework creativity is not actually detached from reason and commonsense but intimately connected with some of the most distinctive features of analogical reasoning, especially its capacity to recognize patterns and properties throughout nature and human intellectual activity.

Aristotle identified two argument forms of analogy: the argument from example (*paradeigma*) and the argument from likeness (*homoiotes*). The paradigmatic argument is synthetically described in this way: 'Enthymemes based upon example are those which proceed from one or more similar cases, arrive at a general proposition, and then argue deductively to a particular inference (*Rhetoric* 1402b15).' The argument is therefore different from induction in that it does not seek to generalize, but simply to raise a single case to a higher cognitive level, in order to deduce from it a certain consequence. Even if its strict logical validity cannot be guaranteed, Aristotle nonetheless values its intellectual utility in suggesting new connections in the form of new propositions. The argument from likeness obeys the following structure: 'Try to secure admissions by means of likeness; for such admissions are plausible, and the universal involved is less patent; e.g. that as knowledge and ignorance of contraries is the same, so too perception

of contraries is the same; or vice versa, that since the perception is the same, so is the knowledge also. This argument resembles induction, but is not the same thing; for in induction it is the universal whose admission is secured from the particulars, whereas in arguments from likeness, what is secured is not the universal under which all the like cases fall' (*Topics* 156b10–17). Thus, in this type of argument the attainment of a provisional general proposition, whose intermediate character precedes an ulterior deductive inference, is less important, and awareness of the absence of such a possibility of universalization is a defining element. Combined, these considerations provide the fundamental features of a 'common-sense model' for evaluating the plausibility of analogical arguments, according to which 'the strength of an analogy depends upon the number of similarities; similarity reduces to identical properties and relations; good analogies derive from underlying common causes or general laws; a good analogical argument need not pre-suppose acquaintance with the underlying universal (generalization).'[19]

In agreement with Aristotle's fundamental remark, it can be said that the analysis of the structure of certain logical arguments is crucial for examining legitimate comparisons (that is, correct analogies and the scope of their validity) between similar but not equivalent objects. Unlike 'strict' and incontrovertible logical sequences (where if the premises are admitted, the consequence emerges automatically and is irrefutable, in virtue of the general structure of *modus ponens*), in the realm of analogies one cannot expect the degree of completeness and certainty that follows from the relation of logical consequence. Analogies offer inferences of variable certainty; plausible, yet not apodictic. However, this weakness is the foundation of their theoretical fecundity. For instead of forcing the mind to their unreflective acceptance, they direct our thought, by exhibiting a series of fruitful and evocative suggestions that can inspire imagination, yet without compelling us in any forceful and irresistible manner.

On these grounds, it may be useful to draw a preliminary distinction between *direct* homology, in which the connection between the antecedent and the consequent is, even if not manifest, at least rather linear, and *indirect* homology, in which such a connection seems almost entirely unexpected. The traditional understanding of creativity in the sciences and the arts, as the highest manifestations of mental productivity, would certainly converge into indirect homology. Given that it is extremely difficult to conceive of a complete ontological separation between the antecedent and the consequent (this possibility of an authentic *novum* is hard to imagine,[20] not even in the context of some of the most widely debated challenges posed by certain logical theorems and the conceptual underpinnings of quantum mechanics), any form of creativity, both in its higher-order (indirect) and lower-order (direct) expressions, must ultimately stem from the elucidation of possible and often unanticipated ways of transitioning from an antecedent idea to one of its potential outcomes. Hence, it has to be the result of realizing logical causality through one or more of the multiple degenerate paths that bind one antecedent to a consequent. Thus, the most creative outcome will be that which, from an antecedent idea, explores the most fertile consequent, understood as the result that maximizes the explanatory potential or the expressive exuberance of the antecedent.

Analogy plays, therefore, a heuristic role, the function of a guiding principle, like a facilitator capable of contributing to the expansion of our knowledge by suggesting new ways of approaching a problem or new frameworks that actually create new problems. Although it lacks in principle a validating role in scientific theories (which can only be founded upon deduction from principles and contrast with experience), it seems of great importance for understanding the genesis of new ideas, the manner in which the human mind accesses innovative thinking. Thus, and while it does not replace a purely deductive method that, enriched with empirical data, helps us arrive at new ideas, it nonetheless appears as an efficient tool for anticipating possible outcomes of a rational assessment. Along these lines, analogy can be regarded as that

general structure of imagination through which it is possible to identify homologies between objects and categories loosely or narrowly related within a certain 'virtual space' (or the realm of potential objects yielded to imagination); this homology, or similarity between the constitution and properties of objects, is susceptible to suggesting connections between them, thereby allowing the mind to advance the precise itinerary or rational sequence by which one can reach them in a strictly logical manner.

Hence, the authority of analogy in our mental processes does not reside in its epistemic value as validator of scientific innovations. Rather, it nests in its ability to expand, through an imaginative treatment of the available information, the potential ways and results of our inquiry. Thus, analogy stands as a compass in the dark and stormy ocean of science and imagination, but this instrument can never be considered infallible. Indeed, it is important to insist on this fact: its hypothetical character implies that, unlike in strict logical argumentation, in analogy the consequences do not have to be inexorably deduced from the premises. If one may feel tempted to contemplate logic as an immense tautology based upon the principle of identity, the nature of analogical reasoning can help us appreciate the value of its intrinsic openness, of its provisional status, of its 'precarious' position when compared to the robustness of the relation of logical consequence. In this way, its deductive weakness contrasts with its inductive strength, its vigor to stimulate human imagination by broadening the scope of its virtual space.

Analogy projects us to the realm of the new, of the unexpected, of that which does not adhere to the rigid canons of logic. Logic provides a syntactic framework for organizing our arguments through primitive notions, initial assumptions and rules of inference, but it imposes a series of presuppositions (precisely in the form of premises and rules of operation) that are not always helpful for making progress in the various domains of human thinking. Analogy, on the other hand, combines elements of pure logical and 'a-logical,' or intuitive experience; the *a priori* and the *a posteriori* seem thus reconciled, even ephemerally, in analogical reasoning. For even if we cannot verify all the situations in which a particular hypothesis holds, if we do not dare to generalize, by overcoming fear of Popperian fallibilism and venturing to propose analogical inductions, it is unlikely that we will add anything valuable to the body of human knowledge. We will hardly expand the circle of our imagination if we do not lend ourselves to establishing comparisons of different scopes, if we do not begin to draw hypotheses that, even if remote from the dream of full certainty that presides over the provinces of pure logic, may widen our present thought about reality and its possibilities. Therefore, even if analogical imagination may not generate truly novel results, it may at least test the capacity of the human mind to explore and discover new possibilities, and it may ultimately produce outcomes of interest and benefit in other domains of knowledge and action. Indeed, the aesthetic pleasure of contemplating new paths for human reason should not be underestimated, as it reveals the richness and exuberance of our inner mental universe.

Along these lines, it seems legitimate to argue that the constructive nature of any analogical reasoning, the fact that it is not limited to deduction on the basis of invincible premises, represents a very fertile area for the study of the unknown. Any portion of reality or possibility that is not rooted in the soil of robust and validated knowledge requires imagination, trial and error; it demands the use of intuition to construct categories that may enhance our current ideas and embrace unexplored options.

And, indeed, without the power of analogy, would have Descartes inaugurated the beautiful unification of geometry and algebra that makes him one of the founders of modern mathematics? Was Coulomb's study of electrostatic forces not driven by analogy with the inverse square law in gravitational attraction? Would have Darwin discovered the evolution of species by natural selection if he had not dared to make analogies between vastly heterogeneous facts,

then timidly related, but in the long run viewed as ramifications of a deeper phenomenon? Did Einstein himself not outline his hypothesis on light quanta as a heuristic principle to explain the photoelectric effect in his famous 1905 article? Not to mention the important role played by analogies in disciplines such as historical linguistics and ethnography.

In this sense, and although science can be said to exhibit a more 'mechanic' dimension, focused on the analysis and management of data, it is clear that intuition plays a fundamental role in establishing hierarchies between the different pieces of information, as well as in selecting them, for example in terms of interpretations that grant more relevance to some data than other. A computer can certainly defeat human intelligence in processing information and discovering unforeseen empirical evidences, but how can we be sure that human intuition, in its creative and often anarchic character, will lend itself to an algorithmic form of intuition? Or, concerning the philosophical disciplines, how can a machine surpass the human mind in the pursuit of depth and originality regarding the connection between ideas? Of course, the improvement of our computational devices should expand incommensurably the scope of some of our speculative abilities, probably by extending our reasoning beyond certain apparent limits or discerning generally invisible connections. This capacity could be immensely profitable, perhaps in the demonstration of certain mathematical theorems. For in many cases it is more difficult to prove a proposition than to formulate it (this is exemplified by Goldbach' conjecture and Fermat's last theorem in the field of number theory); yet, if the problem is examined in depth, the real difficulty lies not so much in how to perform the mechanics of the demonstration, by following an algorithmic process, as in how to enlighten an idea that may guide such a demonstration: ultimately, how to conceive of something new.

Of course, analogy faces considerable boundaries. When Niels Bohr published his famous model, his description of the behavior of electrons and protons within atoms mimicked the picture of planetary orbits in the solar system. Subsequently it was proved that this analogy was insufficient, and quantum mechanics (which despite the lacunae in our understanding of its basic principles is perhaps the most accurate and systematically validated theory created by the human mind for analyzing the behavior of nature -in essence, its temporal evolution- at a fundamental level) was developed and led physics to unforeseen scenarios. In any case, it cannot be denied that the analogy with certain astronomical phenomena drawn by Bohr was useful for incipient particle physics. Although invalidated by experimental and theoretical advances, it still serves as an effective pedagogical tool for those who enter the complex and esoteric universe of subatomic physics.

Only the modesty and lucidity of a researcher will prevent him from abusing analogy. Only prudence and knowledge can protect us from the excesses of comparative reasoning and homological imagination, a vice that has been the root of countless theoretical and practical problems. What is clear, however, is that without employing this kind of inferences, progress towards scientific and aesthetic originality would be significantly hindered, because if analogy were completely eliminated from the range of legitimate operations of the human mind, we would need to await the arrival of indisputable facts in order to propose associations between ideas and images; a demand that would probably paralyze the enterprise of knowledge.

Furthermore, it is important to remember that analogies do not normally obey random connections between disparate realms. In the case of Descartes' invention of analytic geometry, it is clear that both geometry and algebra address quantitative, 'measurable' problems, susceptible to analysis and 'decomposition' into basic elements. A length, a surface and a volume can be quantified. Algebra deals with numbers -known or hidden- that constitute equalities, 'equations' orchestrated by terms that correspond to each other. If we take Euclidean geometry into consideration, we quickly realize that it is a theory about points, surfaces and volumes. Its connection

with physical space, which to a first approximation is perceived by us as a three-dimensional and continuous reality, is therefore evident. Indeed, Euclid designed a form of geometry capable of recapitulating the best contributions of Greek mathematics, aside from systematizing his own discoveries. He unraveled the properties of innumerable figures conceived by imagination and closely related to the material bodies found in our experience of the world. So profound is the connection between Euclid's geometry and physical space that, not surprisingly, Kant enthroned it as the *a priori* form of our sensibility in his *Critique of Pure Reason*. For him, the space from which the human mind starts in its approach to the physical universe was Euclidean space. Since Lobachevsky, Gauss and Riemann we know that it is possible to design geometries which are consistent despite eliminating Euclid's fifth axiom, and contemporary physics, especially the theory of general relativity, has greatly profited from these theoretical developments in the domains of abstract thinking. But in Descartes' days, only a futuristic visionary could have anticipated the appearance of non-Euclidean geometries. The conception of space adopted by Euclid's geometry was so deeply internalized in human imagination that until the 18th and 19th centuries virtually no one dared to challenge its basic assumptions.

Although historical examples about the importance of analogical thinking in mathematical and scientific creativity do not guarantee its necessity for the genesis of new ideas, it is interesting to reflect on the capacity of certain types of imagination to anticipate outcomes that need, in any case, to be rationally established, by sustaining them upon more fundamental principles, in accordance with a deductive model. How do these analogical processes work, and why do they sometimes offer new and insightful ways of solving problems and creating new frameworks for understanding nature and thought? Is it merely the result of chance and contingency, or analogy can be contemplated as an extended logic, in which some steps in sequential reasoning are overcome, but not completely suppressed?

In our view, the latter is the best explanation for the relevance of analogy in many great scientific and philosophical innovations. Rather than representing the fruit of brute combinatorial force, analogy follows its own logic, a process of mental selection after exploring 'reasonable,' homological paths, even if this goal is achieved through imaginative connections and is initially rooted in estimates based on probabilistic inferences from a given set of data and within a certain system of rules.

Indeed, and although there is always an uncontrolled and 'chaotic' element in creativity (which resembles the variation pole in evolutionary mechanisms), the degree of 'randomness' must not be overemphasized. It should not be forgotten that the creative process of an individual mind is based upon previous works and experiences, and it is therefore embedded in a context. Thus, creative freedom needs to be appropriately structured by its own *unifying rule*, in addition to the selective filters of acquired knowledge and social demands.[21] Hence, it may be contemplated as a combination of cognitive flexibility and adaptation to a certain domain of human activity, defined by a fruitful tension between freedom and rules.

These remarks offer an interesting analogy with the nature of scientific inquiries. For it can be argued that science represents a synthesis of evidence and imagination: of data and hypotheses, of experience and reason, of scrupulous submission to the fact and free speculative exercise of the mind. It is in this successful integration of empiricism and rationalism where the force of modern science and its vigorous method of access to knowledge lie. Modern science is not limited to mere observation, since it critically questions reality. And by refusing to circumscribe its scope of action to the simple compilation of evidence, it has allowed us to advance beyond that which is given, to anticipate and discover unpredicted scenarios.

The richness of this method of creation and filter, of cognitive contraction and expansion, emerges with clarity before our eyes.[22] For it not only purifies our reasoning and grants the

final word to nature, the object of our study, but it also corrects and perfects pure reasoning, that which is not referred to extra-subjective experience. Indeed, it is very easy to succumb to the temptation of thinking that our chain of reasoning is infallible, and that we have exhausted all rational possibilities available in the examination of a particular question. This must have been the stance held by most geometers for centuries, until the advent of non-Euclidean geometries and the relativization of our intuitive conceptions of space and time.

Hence, the process of scientific inquiry is not blind or utterly anarchic. The method of scientific invention, like the general process of human creativity, couples the 'unconscious' element (often in the form of sudden intuitions, which nonetheless tend to be the fruit of an ongoing process of intellectual contemplation of a certain idea or subject) with focused conscious attention, with *rational selection*, which is periodically uninhibited by unconscious treatments, revealing original forms of combination and transformation of our mental representations. The creative mind operates, in short, guided by the feedback of the conscious and the unconscious, whose results are selected according to certain filters, both internal (preferences, motivations, experiences, intuitions ...) and external (cultural influences, assimilated traditions ...). Of course, in the most consolidated sciences it is possible to discern a frame of reference defined to higher degrees of robustness, such that the rules of the game are expressed with greater clarity. In them, available evidence and accumulated knowledge cannot be disregarded for the sake of promoting an expansive form of imagination, which may dominate mental representations and reorganize them arbitrarily. However, the exact boundary between the given and the possible is always elusive and elastic. Thus, science can be considered as an efficient combination of intuition, logic and experience; as a synthesis of idealism, rationalism and empiricism, systems of thought from which it distillates their most powerful ideas, overcoming some of their most evident mutual contradictions.

3. INCOMPLETENESS AND AMBIGUITY

It seems hard to conceive of forms of creativity essentially different from the ones that have been outlined, which converge into a synthesis of combinatorial art, homological imagination and analogical disposition of elements.

In any case, distinctions should be made between the different domains of human activity, and even between different processing modes (for example, if one takes into consideration the prevalence of emotions over cognition).[23] Whereas in the sciences it is necessary to master complex formal languages whose sophistication has grown with the accumulation of knowledge, in the arts there is no clear 'progressive path' that compels the creator to become fully acquainted with a particular language or tradition in order to make a useful and appropriate contribution to that domain. At least, knowledge of the latest technical improvements is not indispensable for making a powerful and profound use of human expressivity, because art offers higher degrees of freedom and subjectivity. Indeed, although progress may exist in the technical dimensions of art, which can increase their complexity and sophistication as to propitiate the realization of more elaborate productions, it is dubious to affirm that a similar evolution has to be seen in the profundity of the subjective expression. For in this realm of flexibility it is the creator who sets his own frame of reference, beyond the objective answer to problems defined in a more strict and universal manner. Thus, it is possible to dispense with a multitude of received data and dare to display an authentically free and innovative exercise of expressivity. Yet, the very act of igniting a novel idea is essentially similar in the sciences, the arts and the humanities, even if its expression and the criteria to judge it will inevitably vary.

Thus, in our view the specific way in which a creative action has been displayed is not the really important factor. It is difficult –or even impossible- to prove that any truly creative thought has followed a single route (emotional, cognitive, spontaneous, deliberate…). Rather, it seems reasonable to state that any expression of creativity emerges as the combination of a multiplicity of human faculties, like emotions and knowledge, memory and insight, careful attention and deep awareness.

When a great mind imagines something that defies the power of human understanding, when Leonardo da Vinci draws in his notebooks a rudimentary helicopter centuries ahead of his time, he is actually observing what already exists (the sky, the mind, the wings of birds...), yet in a different and vivid way. Even mystical imagination is nurtured by symbols, styles and traditions that are already known. Only in very rare examples does a genius need to imagine a new heaven or a new mind. When Shakespeare writes his most beautiful plays or his most moving sonnets, he is inspired by human nature, by tragedies, desires and aspirations that have probably characterized us since the dawn of our capacity for self-reflection. He did not have to look beyond what stood before him. He did not have to imagine a different class of human beings, for it sufficed to deepen into the real manifestations of human life. His creative genius thus resides in his astonishing talent for expressing, through the constrictions of language, profound and even immeasurable ideas. Artistic genius therefore creates not by sculpturing an absolutely new realm but by interpreting, through a mixture of radiant sensitivity, restless training and exceptional intelligence, that which already exists. By uniting seemingly unconnected ideas, by capturing details despised by other minds or by posing bold hypotheses, a great creator learns to see what others do not see. In this innovative freedom, a fruitful tension arises against the established set of rules, a conflict solved by designing a new system of rules, capable of elevating the realm of thought to a new dimension. Thus, a great creator does not restrict his action to the obedience of inherited rules; rather, he integrates these rules with his own system of thinking, featured by new (but not necessarily incompatible) rules, in a fertile *Aufhebung* that unveils new possibilities for human imagination. To quote Schopenhauer, 'talent hits a target no one else can hit; genius hits a target no one else can see.'

If, as many philosophers have guessed, nature abhors leaps, a similar principle can be applied to thought: *intellectus non facit saltus*. Impressed by the glory of creative intuition, which often simulates to magically overcome the severe linearity of logical thought, one may forget that, in reality, this prodigious and radical breakdown of the logical sequence never happens in its entirety. Indeed, the human mind cannot conceive of an absolute leap between ideas, a true logical vacuum, a genuine *novum* that cancels the causal continuity between intellectual contents. Such a possibility, reminiscent of the deepest and maximalist meaning of 'creativity,' only shines as an asymptotic limit to which the human mind may indefatigably tend through the power of imagination. For even if we can identify unusual and improbable forms of molding the raw materials with which our mind operates in the form of images and categories, in reality we are simply reorganizing, in skilful manners, contents that have already been given.

Intuition reorders, recombines, relates and condenses certain elements, but it does not annihilate the connection with its logical antecedents; it climbs the highest peaks and suppresses intermediate steps, but it does not eliminate the fundamental components of the long chain of reasoning that underlies the genesis of a new idea. Thus, it appears as the compass that guides us towards a goal, but without exempting us from traveling through the essential stages of the path. Intuition discovers a new itinerary that can then be rationally clarified; it therefore satisfies an eminently guiding function. There is no doubt that intuition often stands as an impenetrable and enigmatic light, as if in it an invisible hand had torn the veil that separates us from a new and unsuspected vision. Refractory to the canons of a conscious elucidation, it

usually lies hidden in recondite domains of the unconscious. But intuition never comes from nothing. Countless previous reflections crystallize in it; a copious number of antecedents, a confluence of perspectives filtered by the accumulated and sustained vigor of rational analysis. So, intuition emerges as the avant-garde of logic, capable of establishing unusual connections between ideas and phenomena, even if these proposed associations are not entirely detached from previous elements. Along these lines, intuition represents a force that allows us to proceed even when we lack conclusive evidence to justify this progression. It paves the way to reason, but it never replaces reason, for in order to expand knowledge, our intuitive guesses need to be validated by reason. Indeed, it is in the synthesis of reason and intuition, of logic and imagination, where the power of human creativity shines with its most valuable light. At this point one can hear the echoes of that deep Hegelian idea that contemplates intuition as the instrument *par excellence* of art; but thought, in the form of philosophical and scientific discourse, requires concepts, clear, distinct and carefully articulated notions, a rational method and a logical itinerary. Intuitions and concepts offer complementary lights; they resemble the union of art and science, of image and concept, of expression and understanding, of beauty and truth as limits of a series expansion that is never entirely completed, such that it cultivates our mind with the contemplation of new possibilities.

On more abstract and metaphysical grounds, however, one could argue that there must be a clear hiatus between the infinitesimal moment that precedes the emergence of a creative intuition and its effective appearance. From this perspective it should be possible to distinguish such a creative leap, such a disjunction, such a new way of facing a problem or generating an idea. A law similar to that of excluded middle should then prevail. Indeed, a truly creative process, which satisfies the highest demands of brilliance and originality, cannot follow a strictly linear sequence. Rather, it must be asymptotically reminiscent of Leibniz's monads (which can only appear and disappear in a sudden way; cf. *Monadology* 6), as a detachment occurring within the fictitious symmetry that prevailed in the sequence of linear thought, built upon premises and rules of inference. Of course, eventually it may be feasible to elucidate the microscopic itineraries followed by the human mind (and even their cerebral underpinnings), thereby reducing the creative freedom to a necessary path, but in practical terms it seems inevitable to draw a critical point at which creativity truly emerges.

Nevertheless, it is very difficult to demonstrate that even the most sublime manifestations of human creativity are actually the result of 'infinite disruptions,' as if authentically new properties, entirely irreducible to the constituent parts and their interactions, had actually emerged out of nothing. Indeed, these changes resemble the physical notion of 'phase transitions,' which despite exhibiting abrupt transformations in the physical states of systems can nonetheless be explained at a microscopic scale.

To illustrate this question, of profound consequences for the philosophy of science, it may be useful to invoke the notions of '*emic*' and '*etic*' viewpoints, which have yielded fruitful results in the field of cultural anthropology. An *emic* explanation starts from the internal perspective of the social group, 'from within,' while an *etic* explanation aspires to a certain degree of objectivity, by using the perspective of an external observer. It is thus 'from outside.' The emergent properties of a system, apparently irreducible to the sum of the parts that constitute the entire grouping of objects, can be regarded as its *etic* expression. 'From within,' the system is completely determined by the sum of its parts and its relations or interactions (the display of the individual properties of the parts and their connective properties in space and time), but 'from outside' it is inevitable to add at least one property: that of the system as an entity of its own, that of the global picture. This emergence of a new property is not a mysterious appearance, a *Deus ex machina* that suddenly 'struts and frets his hour upon the stage.' Rather, it is the logical

result of considering the system (or any of its subsystems) as a whole, and therefore of introducing a new property: that of contemplating the entire system beyond its internal organization, as an object susceptible to external characterization. Metaphorically speaking, 'from within' the universe seems to have no boundaries, no limit that constrains its analysis; 'from outside' the universe stands as a set within another set, subject to boundary conditions. It is through the observation of the system that the emergence of a new property can be perceived. Such a property is, precisely, the grouping itself of the elements into the system, their integration. Thus, there is no need to postulate some sort of abrupt discontinuity between properties, as if a new *novum* had actually made its appearance and it could not be reduced to the fundamental structure of the system. For continuity is not lost; the additional property originates from the possibility of contemplating the system as an entity of its own.

A compelling analogy can be drawn from the foundations of logic. Gödel's theorems of incompleteness point to the impossibility of completely determining the outcomes of an axiomatic system without introducing at least one additional element, in the form of a proposition which, if consistent, cannot be proven from the system. One must inevitably apply a further level of analysis that transcends the internal organization of the system and provides an ulterior viewpoint. However, and although Gödel's theorems suggest an interesting form of creativity, because an unexpected proposition arises within any formal system founded upon a finite number of axioms, this new proposition stems from the incompatibility of two logical properties within the same axiomatic system: consistency and completeness. It is therefore contained in the logical structure of the system itself, justified by a fundamental duality between consistency and completeness.

Hence, the degrees of separation from previous stages of knowledge and thinking may be large, but never infinite, as in a true *creatio ex nihilo*. It is always possible to identify antecedents and logical pathways, even if some supreme forms of intuition have led a creative mind to make a fundamental leap towards a new idea. Viewed from this perspective, the act of creating is remarkably similar to that of understanding, to the development of an 'insight' into the nature of a connection between the elements of a proposition. Thus, creativity can be conceived as the critical point at which an initially sequential process experiences a qualitative advancement. In it, the atomic apprehension of the elements involved becomes capable of constructing an inflection point from which the overall disposition of the parts, the 'whole,' the solution to the problem in question, can be somehow contemplated. By elucidating the connection between the parts, a structure appears, and a focal angle is acquired from which it is possible to examine everything in a rather simultaneous manner. A certain degree of coordination between the elements is therefore perceived, and a higher level of integration is enlightened, so as to exhibit an organic, or 'ordered,' character. Then, the system becomes concentrated on a point, from which it is possible to understand the overall structure by finding the right associations between the parts, through a unifying principle.

Indeed, minds able to work with different lines of thought, and being capable of extracting the ultimate consequences of each of them, are better predisposed for reaching points of positive reinforcement, at which the initially divergent paths can converge and open up new horizons of reflection. In this situation, a virtuous circle can emerge, a process of intellectual *autocatalysis*, where the specificities of each line of thought serve to unveil new possibilities of thinking. If the mind is limited to the contemplation of a single line of thought, a homogenous development will likely take place, and novelty will be reduced to unfolding the potentialities of what is already known or has already been considered, in a scenario similar to Kuhn's notion of 'normal science.' However, when the mind is able to combine heterogeneous paths of thinking, the outcome may be chaotic or useful, but it is in any case more likely to produce a novel thought.

In this way, an important source of creativity seems to rest in the combination of heterogeneous elements (seen both as individual concepts and systems of thinking), in which one tries to reconcile apparently incompatible ideas by 'opening' the individual elements, with the aim of exploring all their potential ramifications and connections. For if we limit ourselves to following a linear path, we will likely display the expectable outcomes of what we already know, without reaching truly novel results. Therefore, in the analysis and generation of paradoxes, contradictions and ambiguities it is possible to discern an important source of potential creativity. Indeed, any domain of knowledge and thinking operates through concepts and associations that are never complete, meaning that, potentially, they could be expanded and refined. Given that the human mind has not found the ultimate and complete system of thought, capable of embracing all the elements of reality, it is almost inevitable that in any of these concepts traces of ambiguity and incompleteness will emerge, thereby suggesting a potential space for redefinition and creative treatment of ideas.

In order to be useful in a certain domain of human activity, the creative results of imagination need to be filtered rationally. Nevertheless, it can be argued that if reason in its universality were to apprehend everything, there would be no human culture as we understand it, no identity or particularity, since we would not be able to discover authentically free and creative realms of action within the human spirit, as perpetual 'avant-gardes' of the mind. If the metaphysical speculation is allowed, it is not evident that a divine entity would be free; his eyes would scrutinize everything from the point of view of the utmost necessity. Yet, human beings, halfway between impulse and reason, enjoy the advantage of nurturing themselves from two divergent but harmonizing forces. The conflict between reason and creativity is thus revealed as an unavoidable contest within the human mind. For without the imprint of the individual, without some sort of 'irrationality,' would the human species have produced some of its most extraordinary achievements? Perhaps the answer would be in the negative, because rationality ultimately converges into necessity and universality, into the inexorable causal line that ties premises and consequences.

Thinking is a continuously standing paradox. It seems to represent a mixture of linearity and non-linearity, of continuity and discontinuity, in which we strive for developing the consequences of certain premises, yet we also try to design new premises and new itineraries of thinking. This creative tension is one of the most enriching sources of novelty and originality in the human mind.

Furthermore, in the study of higher-order cognitive processes one finds glimpses of a fascinating paradox, pertaining to the coexistence of variation and permanence in the human mind. For although rationality must have developed in a gradual way, as both natural history and evolutionary biology teach us, it has to be possible to detect some invariant structures in mental processes that, once acquired, do not undergo substantial modifications. As soon as abstract intelligence appeared and our ancestors were able to understand logical and mathematical propositions it can be stated that a critical point was reached, a point of no-return in the evolution of our cognitive abilities. Quantitative variations may affect the degrees of this ability to understand (like the possibility of understanding more difficult propositions), yet not the crystallization of the act of understanding itself, which is the basis of any great intellectual creation, in which a new connection between elements is grasped.

4. CONCLUSIONS

Only a deeper understanding of how memory, information, emotions and the parallel processing of mental activity converge will allow us to gain a deeper insight into the nature of creativity, capable of transcending the traditional antagonism between an idealized depiction of genius and a more naturalistic framework for explaining the conditions behind the genesis of novel products in the human spirit. While we lack a precise neurobiological model of the exact mechanism through which a new idea emerges, it is reasonable to expect that a combination of elements drawn from a variety of disciplines (psychology, history, sociology, philosophy…) will shed light on the phenomenology of the creative process. Thus, even if an analytically precise knowledge of the cognitive operations is still remote, at least we can hope to gain useful approximations for deciphering the general features of the systems involved.

Indeed, learning to clarify the neurobiological basis of creativity, along with a more thorough study of the social circumstances that foster or frustrate the emergence of creative ideas, should enhance our understanding of the strategies that lie within our reach to promote forms of divergent thinking, capable of enlarging our fantasy and widening the realm of the possible. From this perspective, analogy, seen as the capacity to perceive of homological relations between objects and properties, represents a very fruitful window to creativity.

Some ages and places have witnessed marvelous artistic, philosophical and scientific effervescence: the literary peaks of the Egyptian Middle Kingdom, the torrent of mathematical, ethical and anthropological fertility displayed during the splendor of Greek civilization, the unique fecundity that blessed the Islamic golden age, the plethora of sublime works created by the Italian Renaissance... Talent calls talent; with its particular magnetism, creativity attracts creativity, those spirits avid of novelty and new challenges. Yet, neuroscientific research can teach us to acquire a growing degree of mastery over this unequaled resource of the human species. Thus, creativity will no longer need to depend on spontaneous bursts of genius or nostalgic reminiscences of an *aetas aurea*, perpetual consolation of utopian wills. For if we can understand how the cerebral mechanisms of creativity operate, why some individuals are born with the ability to develop more creative ideas and actions and how we can cultivate intelligence and originality, we will be able to stimulate our dormant energies without having to await the advent of a new golden age, whose irruption will be in our sole hands. Deciphering the specific genes, neurotransmitters, circuits, forms of synaptic reinforcement, brain areas..., in short, the material elements that decisively influence the evanescent capacity to enlighten original and enriching ideas, offers the torch that, in imitation of Prometheus,' safeguards the sacred fire of the gods, in this case the precious jewel of creativity.

Through science we can learn to unify mind and cosmos. For it is the same human reason, in its scientific and philosophical dimensions, what ultimately helps us elucidate the continuity between the natural and the human domains, by employing the powerful explanatory tools provided by physics, chemistry, evolutionary biology and neuroscience. Thus, a valuable bridge between the natural sciences and the humanities can be built by exploring our outstanding capacity to creatively adapt ourselves to the environment and adapt the environment to our own interests and aspirations. Indeed, what we are witnessing is a process of self-invention that, unleashed by external circumstances and internal impulses, releases the most fertile energies available to the human mind.

In this way, the study of the cognitive mechanisms that underlie the creation of new ideas is meant to constitute an important topic for future research in psychology and epistemology. Ultimately, these questions point to the essence and possibilities of the human mind. Each conquest in the realm of abstract thinking is a triumph of the mind in its exploration of a

potentially infinite realm, that of possibilities, that of imagination, that of universality; that which can be filled with meaning and expressed through symbols that, if correctly harmonized, can even anticipate the real workings of nature. And, indeed, by inventing conceptual structures the human mind is actually discovering itself and the scope of its possibilities. For 'our minds are finite, and yet even in these circumstances of finitude we are surrounded by possibilities that are infinite, and the goal of life is to grasp as we can out of that infinity,'[24] in Alfred North Whitehead's wise words.

Notes

1 In a previous work (*Conciencia y mismidad*. Librería-Editorial Dykinson) I have called this feature of the human mind '*el comparecer no compareciendo*,' that is to say, a form of presence that is not present, or a form of 'being' that is constantly negating itself. This idea may evoke a contradiction, but an outstanding feature of the human mind resides in its ability to question reality and itself. The act of questioning mirrors this notion of a 'law that is judging itself,' whose clearest analogue is the capacity of contemplating opposite possibilities (as the classical dictum states: '*natura ad unum, ratio ad opposita*'). This apparent simultaneity of contradictory terms can only be solved through the idea of time, because time implies the constant negation of the identity of the instant (its flow).

2 Fuster, J. M. (2013). *The neuroscience of freedom and creativity: Our predictive brain*. Cambridge University Press, 154.

3 Cf. Seung, S. (2012). *Connectome: How the brain's wiring makes us who we are*. Houghton Mifflin Harcout. Nevertheless, it is legitimate to pose the following question: am I simply my connectome and nothing else? Am I the sum of my stored memories? Should there not be an instance that always overrides the past and absorbs the present; a 'reality' that condenses what has traditionally been known as 'the self,' such that new accumulated experiences may be merged into a biographical identity? This is undoubtedly one of the central mysteries of neuroscience, narrowly connected with the longstanding philosophical discussions on the idea of the 'self.'

4 Cf. Dehaene, S., & Changeux, J. P. (2011). Experimental and theoretical approaches to conscious processing. *Neuron*, *70*(2), 200-227.

5 Cf. Benedek, M. – Jauk, E. – Fink, A. – Koschutnig, K. – Reishofer, G. – Ebner, F. – Neubauer, A.C. 'To create or to recall? Neural mechanisms underlying the generation of creative new ideas' *Neuroimage* 88, 16.

6 Cf. Kandel, E. R. (2001). The molecular biology of memory storage: a dialogue between genes and synapses. *Science*, *294*(5544), 1030-1038.

7 Cf. Dehaene-Lambertz, G., Dehaene, S., & Hertz-Pannier, L. (2002). Functional neuroimaging of speech perception in infants. *science*, *298*(5600), 2013-2015.

8 '*Puede admitirse como cosa muy verosímil que el ejercicio mental suscita en las regiones cerebrales más solicitadas un mayor desarrollo del aparato protoplásmico [dendrítico] y del sistema de colaterales nerviosas. De esta suerte las asociaciones ya establecidas entre ciertos grupos de células se vigorizarían notablemente por medio de la multiplicación de las ramitas terminales de los apéndices protoplásmicos y de las colaterales nerviosas; pero, además, gracias a la neoformación de colaterales y de expansiones protoplásmicas, podrán establecerse conexiones intercelulares completamente nuevas' (*S. Ramón y Cajal, 'Consideraciones generales sobre la morfología de la célula nerviosa,' published in *La Veterinaria Española*, cited by J. de Felipe, 'Cajal y la plasticidad cerebral,' in A. Gamundí – A. Ferrús (eds.), *Santiago Ramón y Cajal Cien Años Después*, 264). For an overview of Cajal and the plasticity of neuronal connections, cf. Blanco, C. (2014). *Historia de la neurociencia. El conocimiento del cerebro y la mente desde una perspectiva interdisciplinar. Madrid: Biblioteca Nueva*, chapter 12.2.

9 Cf. Squire, L. R., & Kandel, E. R. (2000). *Memory: From mind to molecules* (Vol. 69). Macmillan.

10 Cf. Blanco Pérez, C. A. (2017). Philosophy, neuroscience, and the gift of creativity. *Argumenta Philosophica: revista de la Encyclopedia Herder*, (1), 95-108.

11 Cf. Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic bulletin & review*, *11*(6), 1011-1026.

12 Dehaene, S., Changeux, J. P., Naccache, L., Sackur, J., & Sergent, C. (2006). Conscious, preconscious, and subliminal processing: a testable taxonomy. *Trends in cognitive sciences*, *10*(5), 206.

13 Cf. Zeki, S., & Shipp, S. (1988). The functional logic of cortical connections. *Nature*, *335*(6188), 311-317.

14 Lashley, K.S. (1931). Mass action in cerebral function. *Science* 73 (245-254).

15 Cf. Fuster, J. M. (2000). The prefrontal cortex of the primate: A synopsis. *Psychobiology*, *28*(2), 125-131.

16 I have analyzed this topic in Blanco Pérez, C. A. (2014). *Lógica, ciencia y creatividad*. Librería-Editorial Dykinson.

17 For a systematic analysis of the different philosophical theories of analogy, cf. Bartha, P. (2013). 'Analogy and Analogical Reasoning'. In *The Stanford Encyclopedia of Philosophy*.

18 Hofstadter, D. R. (2001). Analogy as the core of cognition. *The analogical mind: Perspectives from cognitive science*, 499-538.

19 Bartha, P. (2013). 'Analogy and Analogical Reasoning'. In *The Stanford Encyclopedia of Philosophy*.

20 For a philosophical discussion on the concept of *novum*, cf. Blanco Pérez, C. A. (2013). *Conciencia y mismidad*. Librería-Editorial Dykinson, pp.171-175.

21 Both Simonton and Csikszentmihalyi have insisted upon the importance of the social 'selection' of original ideas as a key factor for understanding creativity, beyond the study of the cognitive processes associated to this phenomenon. Cf. Simonton, D. K. (2000). Creativity: Cognitive, personal, developmental, and social aspects. *American psychologist*, *55*(1), 151; Csikszentmihalyi, M. (2014). Society, culture, and person: A systems view of creativity. In *The Systems Model of Creativity* (pp. 47-61). Springer Netherlands.

22 Furthermore, this combination of *creation* and logical and empirical *selection* of hypotheses seems the most parsimonious presupposition underpinning the process of scientific generation and validation of statements. Indeed, the impossibility of justifying this duality of principles from a more fundamental principle is implicitly assumed. Indeed, such a method of constant filtering is taken as a presupposition in itself, valued by its effects and the conceptual elasticity of its potential outcomes, because it nonetheless minimizes the number of additional presuppositions. Therefore, it stands as potentially the most rational initial tenet.

23 Cf. Dietrich, A. (2004). The cognitive neuroscience of creativity. *Psychonomic bulletin & review*, *11*(6), 1018.

24 Whitehead, A. N. *Dialogues of Alfred North Whitehead*. Boston: Little, Brown and Co., 1954.