Rossi, A.
Director of the Department of Neurological and Sensorial Sciences,
University of Siena,
Viale Bracci 16,
53100 Siena, Italy.
E-mail: alessandro.rossi@unisi.it

Attanasio, A.
Department of Philosophy,
Head of the Laboratory of "Neuroethics and Social Cognition,"
University of Rome "La Sapienza"
Via Carlo Fea 2,
00161 Roma, Italy.
E-mail:
alessandra.attanasio@uniroma1.it

The Secret of Intelligence: Towards a New Materialism

New analytic techniques have led to a richness of information from the neurosciences in recent years. Philosophical work on brain phenomena, and their explanation, will need to be highly sensitive to the precise parameters of these empirical findings. We are neither our neurons (the neuron is not an epistemic subject), our genes (we have no special cells), nor our synapses (we are not an electrochemical control room). Our brain is not computational because the neuron changes with each connection, modifying in turn the architecture of the connections. A material process of change in the strength of the connections that might explain how simple brain matter becomes Higher-Order Thought. We are not 'brains in a vat' because we are immersed in a socio-cultural environment where experience shapes us through a Darwinian process of 'creative destruction-selection.' We are therefore our connectome, which seems to be our pragmatic identity, a mixed material-mental form, or rather, a set of 'intentions in action'. The findings of recent experimental studies confirm this view. The enhancement of abstract reasoning, both inductive and deductive, in new tasks of problem-solving makes intelligence fluid, not directly dependent on our experience, our historical-evolutionary baggage: a process that could be defined as 'value-coding,' which Darwin called 'forgotten reasons.' The study, then, of global intelligence (both fluid and crystallized) refutes the hypothesis of higher cognitive abilities being related to connections that are highly and permanently connected. On the contrary, the level of intelligence is correlated with the ability to transfer information to distant areas of the brain by weak connections, that are flexible and adaptable. This shows that the secret of intelligence lies in the plasticity of the adaptation processes, in the ability to incorporate in the present act the variability of the past history of the mind, in other words, a 'flexible nested brain mind'. As a corollary, neuroscience now encompasses plausible theories in many domains, including the mind, especially since the weight of evidence indicates that mental processes actually are processes of the brain. In short, the mind is not a non-physical entity.

KEY WORDS: *intelligence, brain, materialism, evolution, connectome.*

Introductory Note

"Philosophers should go down to the engine room of neuroscience and neuroscientists should climb up onto the deck of philosophy," urged the neuroscientist and Nobel laureate Gerald Edelman.

Since 2012, the workshops of the Laboratory of Neuroethics and Social Cognition organized by the University of Rome *"La Sapienza"* have attempted to put Edelman's suggestion into practice. Albeit from different perspectives and with different tools (neuroscientific and philosophic) we are convinced that only a joint and integrated approach between neuroscience and philosophy will enable us to comprehend the complex issues related to intelligence, cognition and processes of higher order thinking. The dialogue presented here is a synopsis of the work done so far and, at the same time, a first contribution to the understanding of our minds after some innovative neuroscientific findings which are also reported here.

Premise

The philosophical side of neuroscience

Neuroscience is the study of the physiological mechanisms that give rise to a manifold of human capacities, including perception, memory, vision and the emotions. To achieve the goals of scientific understanding, neuroscientists must, by necessity, advance claims and hypotheses that are subjected to scientific experiment. In addition to experimental techniques, neuroscientists need a philosophical framework within which to make sense of the results of their empirical work. In short, a necessary complement to empirical research is a coherent conception of the phenomena under investigation.

The neuroscientific side of philosophy

On the other hand, if the neurosciences make us aware of: (a) how the material processes of the brain generate a mind and a self; (b) how brain activity becomes mental experience of a higher order; (c) how material processes codify ecological, social and cultural habitats, therefore, this is a Copernican revolution for philosophy. Moreover, this, which is truly a 'neurobiology of the soul,' produces great mutations to the philosophical concepts of matter, mind, cognition, emotion, higher order thought processes, so much so that philosophy is confronted by the need for substantial revisions of its own conceptual baggage if it wants to maintain its scientific status and avoid becoming an 'uplifting fable' devoid of any empirical content.

Who are we? Who are we not?

Attanasio: The poem by Emily Dickinson[1] is much loved and cited by the neuroscientist and Nobel laureate Gerald Edelman, to such an extent that he even used it for the title of his book (*Wider Than the Sky*, 2004) because it seemed to capture a sense of the more recent discoveries in neuroscience: the brain absorbs every moment of our mental lives, all of our higher-order thoughts (HOT), and even that special cultural matter that is our moral sense, the values of good and bad, virtue and vice. But then, who are we? Or more precisely, who are we not? Are we only the brain, the body, the mind, or the soul? We know we have a body, we see it, we touch it, we take care of it, yet can we say that our 'identity' is decided by the body? And if so, by what part of our body? By the heart, the breathing, which the Greeks called 'pneuma' and identified with the soul, or by the brain? The heart is felt beating in our chest, and if it stops beating, we too stop living. Breathing accompanies us throughout every moment of our lives, and if it stops we exist no more. The brain, that long mysterious grey matter, is something that we can not see, can not touch, and yet we credit it with the 'governance' of all bodily functions, a sort of control room inside our heads or the electrochemical centre that fuels all bodily functions. In short, are our whole being, our whole culture and its values all enclosed within brain matter? It would be such a simple explanation for behaviour and the choice of values of individuals. After thousands of years of culture, philosophy and science, with the neurosciences, today, it could be possible to fulfil the ancient dream of looking inside our heads and seeing who we are, who we are not, how we work, why we are always torn between good and bad, altruism and selfishness, sociability and unsociability? And yet the brain is only a mass of neurons. What can a neuron know? Could a neuron be an epistemic subject?

Rossi: Some of the most important themes that science currently addresses are the structures, behaviours and evolution of complex systems, like cells, the brain, ecosystems, society, and global economies. Since complex systems can not be thought of as the sum of their elementary components, understanding their behaviour requires not only knowledge of their single components but also of the ways these components interact, as well as of the properties that emerge from such interactions.

Before technologies to record, analyse and model the behaviour of systems composed of billions of interacting elements became available, the neurosciences focused on the properties of the main elementary component of the brain: the neuron. A neuron communicates with other neurons via electrical impulses, also called potentials, and chemical secretions called neurotransmitters, whose effects are not perfectly understood. Electrical input to one neuron comes from many others, each having a specific amount of influence, or weight, on the neuron.

It has long been known that the properties of the neuron are similar in all species, from platyhelminthes to humans. We are not our neurons and the neuron is not an epis-

temic subject. We do not have special cells and each neurone produces an activity that relies on the inputs that it receives from hundreds/thousands of other neurons. Two points need to be made here: first, each neuron produces increasingly complex activity as the complexity of its connections increases; second, neurons have an intrinsic plasticity, that is, a capacity to modify their intrinsic excitability by adapting to the system in which they are integrated. Neurons, therefore, are cells structured to interact with themselves and with other neurons. It follows that, in comparison with other species, a more complex organization of the human brain results in the more complex activity of our neurons.

There is now the growing belief that to understand the human brain we need to map out all of its elements and connections to create a comprehensive structural description of the network architecture. In other words, without understanding its connectivity we can not understand how the brain works. The objective of studying connectivity is to decipher the neural networks that generate thoughts, feelings, and behaviours (see also below).

Attanasio: In short, our brain is composed of neural cells that are neither special nor dissimilar to those of the brains of other species. This confirms the Darwinian hypothesis of a common origin for all living forms. Furthermore, in complex systems the number of elementary components is not as important as the mode of interactions that produce/establish/constitute the emergent properties. Once again Darwin was right: "it is certain that there may be extraordinary mental activity with an extremely small absolute mass of nervous matter … the brain of an ant is one of the most marvellous atoms of matter in the world, perhaps more so than the brain of a man" (Darwin, 1871). Our attention, therefore, should not be focused on the neuron but on 'groups of neurons,' or 'populations of neurons,' as demonstrated by Gerald Edelman in the wake of Darwin's theory of selection. We should also be looking at the complexity of interconnections because it is from this complexity that new properties emerge. In practice, there is a continuous production of complexity with properties emerging from it. This is plasticity. Therefore, 'intrinsic plasticity' is used to refer to 'plasticity intrinsic to matter' and not to something esoterically intrinsic to the neuron. We would like to avoid this misconception because in philosophy the term 'intrinsic' often has spiritual or metaphysical connotations that conflict with science, and these properties are often regarded as some sort of 'mystic properties'.

Rossi: Intrinsic plasticity refers to a persistent modification of neuron electrical properties induced by the same neuronal electrical activity. The molecular mechanisms underlying this intrinsic plasticity comprise the highly specific transcriptional or post-transcriptional regulation of ion-channel expression, trafficking and function. It is, therefore, a phenomenon of self-regulation and it is observed in 'in-vitro neurons' as well as in 'in-vivo neurons' of animals and humans (e.g. Rossi, 2012). Although the exact functional role remains speculative, the goal of the intrinsic plasticity mechanism is to enforce a sparse distribution of the neuron's activity level.

Attanasio: One could therefore say that, because of its capacity to adapt, the material plasticity intrinsic to the neuron, is also the basis for cognitive processes, such as memory and learning. So, if the neuron is not an epistemic subject capable of cognition, choice and action, then, it is the material plasticity intrinsic to the neuron that determines learning processes. In other words, it is simple – yet plastic – brain matter. The problem shifts, therefore, towards the synaptic connections. Is it there that all our mental capacities reside? Or rather, is all our knowledge, our arrogant specialties, enclosed in a series of electrochemical sequences? In short, are we our synapses?

Rossi: We are not the electrical signals produced by our neurons. To paraphrase von Waldeyer, a neuron becomes part "of the machine of thought" when it is inserted into a network of wired interconnections with other neurons. These interactions occur via the complex scheme of neuronal electrical activity and follow pathways determined by the context of the architecture of our brain connections. To use the metaphor of the 'stream of consciousness' coined by the American psychologist William James (XIX sec): the architecture of brain connections represents the flow path (the riverbed) of the electrical activity of neurons (water). Just as water changes a riverbed, the electrical activity of neurons 'sculpts' our connections. Therefore, the organization of connections between the neurons affects their activity and, in turn, their activity conditions the organization of connections. The brain, unlike what was previously thought, is a system in perpetual transformation (e.g. Santarnecchi et al., 2014).

Attanasio: Here we aim to disprove two important philosophical positions. The first is the 'language of thought' hypothesis proposed by Jerry Fodor (1975), which implies the existence of a true 'machine of thought' completely separate and independent from the brain and body from which our human 'speciality' emerges. The second considers thought as the most noble and ethereal part of our being human, a part that can only be 'immaterial'. The picture, in fact, seems to be quite different. The 'thinking machine' is activated only within a complex network of connections that continually changes its architecture, like water changing a riverbed. Therefore there is no 'universal grammar' (Chomsky, 1988) and no 'mind language' (*Mentalese* by Jerry Fodor) or logical thinking. What's more, there is no such thing as the immateriality of thought. In fact, if life moulds our connections through our experiences, the neuron, then, is not simply a transmitter of electrical signals as was previously thought. The neuron, by changing its nature, is no longer only a conductor of forces, because it also transmits its 'modified materiality' with every discharge, thereby eliciting/originating/giving rise to the material modification of subsequent connections. Hence, the image of an electrical network of neural connections is simplistic and rough: here we are introducing 'biological change' inside the 'force' of the connections, and 'material change' inside an electrical phenomenon. It is as though an electrical network, in itself almost immaterial, implements and drags with it all the material variations of the process. These results of your research seem rather

innovative, ripe with consequences, even philosophical ones. The process described here, therefore, could tell us something more about how higher-order thought emerges from simple brain matter, while avoiding a primitive form of materialism (everything is material, the mind is just smoke), metaphysics, idealism, spiritualism (everything is beyond the physical, everything is idea or spirit). In fact, the continuous variations in the architecture of the connections bring out a very special type of materiality. As Gerald Edelman (2000) would say, matter from which imagination, higher-order thought and consciousness emerges, without, for this reason, us falling into a 'smokescreen' (W.O. Quine, 1953) or becoming 'spirit' or 'soul'. There remains, however, a doubt. Could this group of connections, in which electrical events flow, be simply 'signals' whose path could be decoded, computed and replicated by computers?

Rossi: The Human Brain Project, launched 18 months ago, was a massive neuroinformatics project to simulate the entire brain in a supercomputer. Now the neuroscientific community has judged its scientific direction to be wrong. In other words "The human brain project is failing and must be fixed." (Editorial, Nature, 2015). A replica of a human brain in a supercomputer is theoretically possible, provided that all interconnections have been identified (their number corresponds to the stars contained in 1500 Milky Way galaxies) including all variables known up to now. The brain 'feeds' on information: it acquires, interprets, stores and processes information from the worlds both outside and inside the body. One of the historical problems of biological neuroscience (which risks being compounded by computational neuroscience) is to consider brain functions as the product of an 'isolated brain.' However, every attempt to develop new generations of electronic methods that can make more efficient and widespread use of neurobiological data, needs to be supported.

Attanasio: Here we introduce another important topic for both the neurosciences and philosophy. Information is not isolated 'inside' our head, and is not the software that runs inside the hardware (the brain). The brain-mind feeds on information coming from the body and the outside world. In this intertwinement of the brain-mind, body and world, information is interpreted, processed and stored. The body enters the brain-mind (Damasio, 2010), just as the world enters the mind-brain. As Panksepp (1998) says, progress in understanding the nature of cognitive processes can only proceed through the integration of mental, behavourial, and neuroscientific approaches, an interweaving of BehaviourBrainMind. This complex architecture of connections and tracks through which the Jamesian consciousness flows, on which we graft our exchanges with the outside world, seems to be a continuous construction and pragmatic concretion, more than a mass of signs and signals. Thus pragmatism enters brain science, bringing with it individual experiences, behaviours, systems of social values. A doubt remains: could this intertwinement of correlations between the network of connections and the behaviours of our lives be determined, directed and governed by our genes? Could it be that

the genes mark out the path where the interaction between connections and behaviour occurs? Is it the genes that conduct the "dances" of our lives, as Dawkins (1976) and the majority of geneticists affirm? Could our individuality and 'specialty' therefore be intrinsic to our genetic endowment? If this were the case, we would be facing a deterministic materialism which would limit the space of individual liberty.

Rossi: Although genes seem to have an extraordinary power over our destinies, we are much more than our genes. This is so for a simple reason: our genome does not change, while the connections between the 100 billion neurons in our brain change throughout our lifetime. Our genes determine the direction of the connections, the wiring of the brain, but experience sculpts and dynamically selects the architecture of our connections. For example, the evidence that intelligence can be enhanced by techniques of neuromodulation (see below) shows that even the higher brain functions are not rigidly predetermined by genes. Indeed, if this were the case, intelligence should be stable like our genome.

Attanasio: Hence, the great demiurge that selects the paths and sculpts the traces of the architecture of our cerebral connections is experience. Therefore, to say that everything is 'in our head' is misleading because the connections 'inside' our head are continuously correlated with our life experience 'outside' our head. And this correlation can modify the architecture of our connections. It is much more than a simple entrance to the world of the brain-mind. It is the correlation, in fact, that brings the changes to the architecture of the connections. A complex interaction between brain, mind, body and world which is constantly changing. This debunks the myth of the brain as the command post where mysterious homunculi send control signals to the body and mind (Dennett, 1978). This 'instructionist' approach lacks the complexity and variability of the architecture of the connections produced by the continuous selection and variation of our experiences in the world. Furthermore, this approach stumbles over the 'matryoshka' effect and falls into an infinite regress: which homunculus commands the first? And who commands the second? And so on to infinity. In the same way, it invalidates the hypothesis that the brain resembles a black box, in which there are only neutral causal relationships, or, in other words, a box isolated from the body, from the world it lives in, as well as from other individuals in society. In short, the "brain in a vat" (Putnam, 1981) is not plausible. No brain can exist without anchorage in the world. The biological materiality of the brain is imbued with sociality, interactions with other individuals in society. The brain pervades the social world, and at the same time, history, culture and society enter the brain. As was well expressed by Bertrand Russell (1921) since man has always acted historically, his brain in neither a system of processing information, nor a computational system.

Rossi: In general, our brain acts via structured and selective interactions between neurons that are integrated in a system of complex connections that interacts with itself and with the external environment. In other words, the environment 'enters' the brain and the brain 'extends' into the environment. Life shapes our connections through experience. For example, during the first months of life, synaptic connections are created at an impressive speed: half a million per second. This rate then decreases progressively and experience begins to eliminate the 'useless' connections until we become adults, when only 60% of the connections of infancy actually survive. In adults, this 'creative destruction' takes the form of a 'creative selection', which continues throughout our lives. But our experiences are not only the result of information received and processed from the environment through our sense receptors. Even our movements are powerful factors in the selection of neuronal connections. Charles Scott Sherrington, Nobel laureate (1932) said that "to move things is all that mankind can do....". To move muscles, our brains have to successfully do three things: imagine the movement (i.e. imagine a future), move the muscles (i.e. live in the present) and get feedback from that movement (i.e. remember the past). The amazing thing is that once a human being begins to move, language and all the countless by-products of the brain's ability to move muscles also emerge.

Attanasio: It would seem that this process, besides being Darwinian (destruction and selection), also produces creativity as an effect of movement targeted towards research and exploration. In actions, therefore, we could find the forger who, researching, developing and depositing experience, leads to 'creative selection.' An interesting process of "intentions *in* action" and of "actions *in* intention" (Pansepp, 2003), completely different from higher order intentionality (i.e. intention *to* act). And this could help us to better understand the 'mixed' structure (material-mental) of the process.

Rossi: Within the intricate architecture of connections, as of yet nobody knows where the complicated sequences of electrical activity flow and interact to programme our motor actions, to recall the past, to analyse the present and imagine the future. But researchers are optimistic; thanks to the very challenging 'Human Connectome Project' launched by the neurosciences in 2009 – in which many American and European research institutions are involved, including our laboratory at the University of Siena – we have begun to formulate some answers.

Attanasio: What is a connectome?

Rossi: The term connectome is used to recall, on a large scale, scientific efforts to decode the human genome. The connectome is a detailed map of all the neurons in the brain with their connections (Seung, 2012). In man, this is mainly studied using two complementary methods of neuroimaging (resting-state functional connectivity and dif-

fusion imaging), which allow the representation of the bundles of axons (connections) in different colours, according to the direction of the synaptic flow. As already mentioned, the connectome changes continuously during the course of our lives. These changes occur because brain connections can be created, strengthened, weakened, or eliminated at any time. This happens primarily at the synaptic level (the point of contact between neurons) through a process called 'synaptic weighting', i.e. the increase or decrease in the function strength of contacts between neurons. These connections can weaken and disappear but can also regenerate. Moreover, in animals, it has been demonstrated that brain areas can be 'rewired' after an experimental disconnection. Finally, although for decades it was generally thought that neurons could not regenerate, it has since been discovered that in primates adults do grow new neurons, and that part of this regeneration takes place in the hippocampus and olphactory bulb. All these mechanisms (weighting, regeneration, rewiring, neurogenesis) are the platform for the plasticity of our connectome, i.e. what allows the formation of new associations between neurons. Obviously, stable connections must exist, where memory is stored.

To sum up, we are not only our neurons, we are not only our genes, we are not "brains in a vat": we are our connectome. Our connectome is unique and contains a huge amount of information. That information includes our memories, personality and other aspects of our identity.

Are we the soul or are we the brain? Are we spirit or matter?

Attanasio: Hence, "we are our connectome." This is not an affirmation as such, but the result of scientific evidence, consequently much of our understanding of the brain, mind, action should be updated. We are now faced with the need for a thorough review of the concepts matter and spirit. To recap, there is a continuous correlation between the complex architecture of the connectome 'inside' our head and the world 'outside' our head, which we explore through movement. Moreover, the change of architecture 'in' our head is the direct effect of our actions. Therefore, connectome seems to have 'mixed' material-mental components, a 'circular' structure of feedback, inside-outside/outside-inside, a process that is 'recursive': destruction-creative selection. It seems quite clear that beyond the selective Darwinian process, we can speak, in agreement with Edelman (1992), of a particular form of materialim, "sophisticated materialism" that (a) implements mind over matter: all our mental being is represented by the necessarily biological architecture of the connectome; and (b) implements matter in the mind: experience and individual actions modify the mental traces of the connectome. As Searle (2004) says: there is not a mental world and a physical world: there is only one world. But we could also speak, according to Edelman, of "conditioned realism" (Edelman, 1992): reality in continuous transformation, conditioned by the multiple network of interactions between individuals in society, and by feedback from this conditioning network on the traces of

connectome. Moreover, the strong emphasis that is placed on motor action, as the ineradicable basis of exploration in the world, makes one think of a 'sophisticated pragmatism' (and perhaps Edelman would also agree with this definition). The process, however, is not all resolved with 'external' actions because these produce biological modifications of the 'internal' paths traced in the connectome. Therefore, we must change the philosophical concepts of matter and spirit and cast off definitively the dualism body/soul, matter/spirit, action/thought. Darwin was right then when he stated "the mind is function of body" (2010, *Notebook* N 5): "thought, however unintelligible it may be, seems as much function of organ, as bile of liver" (2010, *Notebook on Moral Sense*, 37). In short, there are no immaterial souls.

Rossi: I believe that everything that concerns us is contained in the architecture of our connectome and that its complex, and in part obscure, internal dynamics generate all that we are capable of expressing in thought and action. With this in mind, I would like to return to the previously mentioned sentence "*to move things is all that mankind can do*" (Sherrington). All our thoughts and emotions need to be expressed (whether it be to articulate a sentence, write, paint, play or shake hands) in order to acquire social value. Without the possibility of 'moving things' the brain would close within itself. We recalled this concept to challenge the widespread simplification that a thought arises from a complex operation that is incomparably superior to a motor action. Even the most simple motor action, like reaching out to grasp an object, involves a complex sequence of operations: one must elaborate the idea of the action to be performed, acquire the spatial coordinates of the object to grasp, devise a related motor project, organize a plan of execution, activate the right muscles in the right way, and check that the programmed trajectory is consistent with that which is actually performed. Obviously, the complexity of the operation increases with the complexity of the movement, and perhaps the same holds true for thought (e.g. Gelli et al., 2005). It is important to mention that imagining a movement without performing it produces the same changes in the neuronal activity of the cerebral cortex that occur when the subject actually performs that movement (Rossini et al., 1999). Perhaps, there might be common operating mechanisms that underlie the production of both thought and movement. Consequently, the separation of mind and brain is no longer helpful to scientific research: the foundation of human cognition lies in the dynamic patterns and interactions shaped by the connectome.

Attanasio: To illustrate a further enrichment of this process: the acquisition of social values through our actions in the social world makes the process a form of sophisticated or conditioned materialism-pragmatism, as already intuited by the neuroscientist Gerald Edelman (1998) and the philosopher John R. Searle (1997). The 'values' that give a sense to our social lives should be converted to 'facts,' by the reality of our actions and these in turn influence the changes in the material traces of the connectome. The flow and changes in the connections are continuous and therefore the acquisition of values is subjected to ongoing change and Darwinian selection. In other words, values are neither

fixed nor unchangeable. All ethics and religious norms and prescriptions fall/collapse/crash as closed boxes, their rigid and prescriptive values are often unchangeable and irreconcilable with such a complex feedback of changes and selection. In conclusion, if the history of the brain that sends and receives signals is false because, inside that transmission and reception, signal histories of 'material and value' variations have occurred, then not only must the concepts of matter and spirit, soul and body change, but also the history of dualistic facts/values is to be reviewed. It is not by chance that today we speak of the 'social brain' (Panksepp, 1998). As Darwin would say, the development of the brain-mental structures and, at the same time, sociality, are part of a process of continuous mutation and selection. A hybrid of biology, sociality and culture.

Rossi: Simply a matter of brain matter? Given that, "If the human brain were so simple that we could understand it, we would be so simple that we couldn't" (G.E. Pugh, 1977, p. 154). As already mentioned, the basic elements, the neurons, of our brain are actually universal structures, similar to those of other species. But it is our own special architecture of connections between neurons that makes us who we are. In this complexity, we can find the biological bases of our identity, the 'book of life,' and one day we will be able to read it.

Attanasio: Hence, if Sherrington was right in saying that all that we can do is move things, and if this movement in the world is neither inferior nor less complex than thinking, then many things change in philosophy and also regarding common sense as well. Additionally, we can better understand the process, in fact, by which our more 'ethereal or abstract capacity' (that which old philosophy would call the soul or spirit) can emerge from simple brain matter. What is more, that matter would appear to be nothing 'special' in the universe of the brain matter of living beings. And this is a step further, we believe, towards understanding the biological basis of our mental identity. The evidence long sought after that the mind, imagination and creativity can emerge from matter is now clear: at the root of the act of speaking, writing, painting and playing is the same 'motor project' that forms the basis of our behaviour in the world. Furthermore, the continuous flow of connections and 'material changes' between the brain and actions, together with continuous selection, shapes the 'mental traces' inscribed in our connectome. A 'sophisticated materialism' including all of our 'high capacities' within matter, while excluding all simplistic and imprecise bottom-up and top-down processes. In this process, there is no rising from raw matter up to empyrean heights (the transcendence of matter), nor an infusion of higher order faculties into matter (the soul infused by God or living beings infused by essences of metaphysical minds).

Rossi: During the last 3 million years, the growth of the human brain has perhaps been one of the most extraordinary events in the history of life. However, size per se explains nothing about the special performances of our brain. As mentioned above, recently the neurosciences launched the most ambitious project that man has ever conceived.

This project entails a revolution in the theories and methods for understanding the brain and its functions: the introduction of the connectome, an ever-changing architecture under the influence of our experiences and thoughts, matter and spirit, nature and culture.

Attanasio: The brain, or rather our connectome, seems to be an ideal subject for containing all of our mental life, identity and sociality. And this leads to another philosophical question. Do we have a self identity? And how is it possible to conserve the traces of our mental, emotional and social life in the dynamism of the connectome? And how is it possible to record and conserve all of our mental life if the properties of the neuron are not stable and the connectome continually modifies its architecture? Does this jeopardize our autobiographical identity? Are there areas of the brain where stable memory or, as Darwin would say, the "memory of the species" settles?

Rossi: Research is not limited to the study of the morphology of the connectome but it also looks at its relationship with our identity. Probably we will have to wait a long time before we discover 'how the brain's wiring makes us who we are'. Our individual, personal development and experiences are inscribed within each connectome in an unrepeatable way. Even our memories could be retained in the form of specific geometric organization of our connections. For example, evidence from the few persons resuscitated after drowning in icy water (i.e. after suspension of all biological activity including the brain's electrical and synaptic activity) show that all traces of memory are retrievable. This means that memories are actually preserved inside the specific, geometric organization of the brain connections. In fact, with the flow of the electrical activity along these specific organizational geometries, all memories resurfaced. In other words, we possess our own individual connectome: i.e. we are our connectome.

Attanasio: But if memories have a material trace, what about our emotional history? An emotion is elusive, ineffable. Yet could it also physically contribute to the architecture of connectome? Is it inside or outside the warps of the brain? William James (1890) had already understood that all our mental life is literally 'interwoven' with our bodily frame. And he regarded the entire organism as an "organic sounding-board, which every change of our consciousness, however slight, may make reverberate," a unification, therefore, of body, mind and action. The connectome is certainly similar to this reverberating organ, enclosing all things 'inside' and reverberating them 'outside,' all the motions of our body and brain, our emotional and mental life. Hence, the body and the brain can be likened to a musical instrument.

Rossi: Music does not exist by itself, but is created by our brain. Indeed, for music to exist, humans must possess the neural substrate able to carry out the necessary operations. The musical instrument emits a rhythmic sequence of compressions and rarefactions of the molecules that propagate in a medium (air, water) and it is the brain that 'creates' music; music is a simulation produced by our connectome. It is possible that

music originates in the brain from the superposition and resonance of biorhythms generated by intrinsic or 'internal' electrical activity (synaptic potentials and action potentials) with rhythms generated outside and transferred to the brain by the acoustic receptors of the ear. A recent study (Abrams et al., 2013) has identified a very distributed network that contains the structures engaged in the planning of movements, memory and attention, which is activated in a similar way in all subjects listening to music. This relationship between music and the brain is not new. What is new is the fact that it is now widely used for neurological rehabilitation. For example, the rhythm of music, more than its melody, can allow people with Parkinson's disease to regain a sense of balance and a symmetrical step. The rhythm of a metronome or drum is capable of conferring harmony to the discordant movements of patients with severe motor dystonia. Other clinical studies have demonstrated how music can promote verbal and non-verbal language in autistic children. In fact, there has been a great deal of recent interest in understanding the interactions between the auditory and motor systems. Unlike visual stimuli, music has a remarkable ability to drive rhythmic, metrically-organized motor behaviour.

Attanasio: Therefore, from a philosophical point of view, in music we could find the concretion of that 'mixed form' that remains a bit obscure if we look separately at the material body, brain matter, or the ineffable and intangible ethereal essences of spiritualism. The incessant work of the connectome to continuously recreate itself seems to have found in music its most appropriate tool for 'resonance' since at the same time it is both physical and mental, internal and external, without censorship. There are always new grooves being dug in the connectome, and that work is continuously reverberated externally in a mixture of biological, physiological and cultural interconnections. Music is a continuum, the action and vibration of hidden memories, senses, thoughts, fantasies and actions. In short, one could think of the connectome as the music of our being, amalgamating body, emotion, mind and action. The verses of Emily Dickinson return once more: the connectome is the music, it's the sound that contains every syllable of our complicated lives.

Rossi: one of the remarkable aspects of music is that it evokes emotions. A performer will often experience emotions while playing, which in turn can be communicated to an audience. Music can elicit not only psychological mood changes, but also physiological changes, for example in the heart rate and respiration. Music-induced emotions have been shown to recruit the reward-motivational circuits (Salimpoor et al., 2013). However, the mechanisms whereby such emotional transfer may occur are far from being understood.

Attanasio: As Panksepp (2012, p. 396) states, "the dynamics of music seem to have direct access to the affective structures of our core-consciousness." This brings us to the subject of the 'archaeology of the mind'. Today there is an attempt to observe not only the explicit aspects of values, judgements and human behaviours, but also the implicit ones hidden in the folds of the history of a species in a given habitat. A sort of

geology of the mind that already started with Darwin's theory of emotions and whose most prominent scholar, today, is Jaak Panksepp. It was no coincidence that Panksepp started with the study of affective states (*Affective Neuroscience*, 1998) and progressed to the archaeology of mind (2012) with the intention of understanding its biophysical substrates of emotional experiences and higher order thinking.

Rossi: It is possible that 35.000 years ago, in an attempt to export emotions, the Aurignacian culture produced sounds; perhaps with the bone of a vulture they played a pentatonic scale, in a moving evolutionary parallelism with blues. People know from experience that music can evoke powerful memories. What generally seems to happen is that a familiar piece of music acts like a soundtrack for a mental movie. Music is a powerful reminder of autobiographical memories. The medial prefrontal cortex is probably one of the locations for processing music and music-memory communication. .

Attanasio: Therefore, one could say that from music (and from the connectome) all the 'geological' layers of the mind and the ego emerge, in other words, all the archaeology of the history of a species and, at the same time, a sense of that biographical memory.

The secret of intelligence

Rossi: Actions, perceptions, emotions, thought, fantasy, language, and semantic and autobiographical memory are classically listed as cognitive functions. Our intelligence depends on our ability to use these tools. We should note that this is far less a philosophical or semantic problem than a scientific one. According to the current definition, intelligence not only expresses 'the capacity for adaptation to an environment' but also our abstract and creative thinking, our ability to plan for the future. A study conducted in our laboratory (Santarnecchi et al., 2013) demonstrated that by experimentally enhancing the synchronization of the neuronal activity in the frontal cortex at a specific frequency, subjects improved their abilities in abstract reasoning: i.e. the ability to solve problems never tackled before using both inductive and deductive reasoning. In psychology this is referred to as fluid intelligence. This fluid intelligence, contrary to crystallized intelligence, does not derive from experience, study or the cultural and educational baggage acquired during the course of one's life.

Attanasio: This discovery is of great importance for the neuroscientific understanding of intelligence and higher-order cognitive functions, and as such earned the cover of *Current Biology* (2013). But it seems to be of great importance also for its philosophical implications. Moreover, it also appears to be the experimental confirmation of pre-Darwinian and Darwinian lines of thinking which have not been studied adequately so far. Research on the intelligence of the species (memory, emotions, reasons, con-

science, moral conscience) is centred on the new theory of instinct that Darwin already started to elaborate in his *Notebooks* from 1838. What are the instincts? "When an individual cannot give reason, though he feels he is right… when the meaning or reasons are forgotten … this power of the mind faintly approaches to instinct" (Darwin, 2010, *Notebook on Moral Sense*, p. 11). "Instincts, certainly appear a sort of acquired memory, a permanent secretion of thought … Conscience is one of these instinctive feelings …" (Darwin, 2010, *Notebook on Moral Sense*, pp. 37-38). Instincts, therefore, are "forgotten reasons," consciousness, or moral conscience: "If judgment remains, where reason is forgotten, it is conscience, or instinct" (Darwin, 2010, *Notebook on Moral Sense*, p. 61). Completely overturning the old theory of instincts, Darwin made instincts the highest point of an animal's mental abilities (2011). Instincts are 'reasons' because they are the judgements and choices of past generations. Reasons are 'forgotten' because the causal succession is lost in a long history of sedimentation and transmission. And yet those forgotten instincts-reasons emerge in the present unconsciously, implicitly, obliquely without experience and without any inductive or deductive 'reasoning,' like the features of fluid intelligence discovered by you (Santarnecchi et al., 2013, 2014). These forgotten reasons, then, for Darwin, are not only the conscience of the species, but also its moral conscience, or rather, the highest point of our being. This was a genial intuition on the part of Darwin, which, nevertheless, had a philosophical forerunner in David Hume, the most famous Darwinian before Darwin. Hume spoke of "animal reason" or "instincts of reason": "reason is nothing but a wonderful and unintelligible instinct of our souls" (Hume, 1739-40, *Treatise*, 1.3.16.9). How does the reason-instinct emerge? It emerges from our mental customary transitions, and consists of those inferences "without experience or reasoning" that emerge obliquely, implicitly and unconsciously. An accumulation of the sedimentation of knowledge, experience, trial and error that materializes in an act of the mind. This is the secret of intelligence.

Rossi: Although modern technology does not yet allow us to navigate on the surface of man's brain connections, it is nevertheless already possible to analyse the circuits implicated in intelligence. Recently, we provided experimental proof that the level of global intelligence (fluid and crystallized) is affected by 'weak' brain connections, or rather, by a network of flexible links between different regions of the brain that are very distant from one another (Santarnecchi et al., 2014, 2015). Evidence that levels of intelligence are correlated with the ability to transfer information between distant brain areas via weak connections (therefore flexible and mouldable), disproves the general hypothesis that the variability in the cognitive abilities (mental faculties of a higher order) of human beings is linked to the organization of a group of areas highly interconnected in a stable manner. Instead, intelligence would seem to be tied to the ability to process and manage flexibly more complex information in a distributed form, i.e., a form that is not segregated in specific cortical areas. To confirm the importance of the distributed organization of higher brain functions, in an article recently published (Santarnecchi et

al., 2015), we observed that the brain connections that endow the brain with the ability to adapt to perturbations (brain resilience) are much more widely distributed and diffused in people with higher levels of intelligence. In other words, in these people the brain shows a greater capacity to withstand mechanical or vascular injuries. This is perhaps one of the answers to the question posed by I. Deary: "Why do intelligent people live longer?" (*Nature*, 2008).

To sum up, our results showed that, for the most part, the variance in intelligence levels can be explained by the distributed communication efficiency of brain networks that are built using moderately weak, long-distance connections, with a smaller contribution from stronger connections. These findings challenge the traditional view that strong functional brain connections play a prominent role, while highlighting the importance of both strong and weak connections in determining the functional architecture responsible for human intelligence.

Attanasio: For these very important scientific results you earned another cover (*Human Brain Mapping*, 2014). Yet they are also significant for philosophy. In practice, adaptation, or rather, the ability to solve new problems, is the primary factor of the intelligence quotient. Adaptation is part of the historical 'baggage' of intelligence, our 'fluid intelligence,' which emerges in the present 'without experience or reason.' The inheritance of species appears to be very close to what Edelman called "nested values," in a process that Panksepp described as "value-coding mechanisms," which allows organisms to categorize world events efficiently and which is crucial, therefore, for the survival of every species (Panksepp, 1998). Hence the 'nested value' in the eagle, its fluid intelligence, is the light that allows it to survive, while in the bat it is darkness. Today, the 'nesting process' of values is being studied by Panksepp, with the intention of discovering the ancient and multiple geological layers of our minds; that 'archaeology of the mind' which should shed light on the processes that are at the basis of nested brain mind. Returning to Emily Dickinson, that is why the brain is "deeper than the sea," because it absorbs. Thus, just "as sponges ... do," the brain absorbs and 'nests' within itself all of its past history. And this is the secret of intelligence.

Appendix

1 The Brain is wider than the sky,
For, put them side by side,
The one the other will include,
With ease, and you beside.

The brain is deeper than the sea,
For, hold them, blue to blue,
The one the other will absorb,
As sponges, buckets do.

The brain is just the weight of God,
For, lift them, pound for pound,
And they will differ, if they do,
As syllable from sound.

(Emily Dickinson, 1862, XLIII).

References

Abrams, D.A., Ryali, S., Chen, T., Chordia, P., Khouzam, A., Levitin, D.J., & Menon, V. (2013). Inter-Subject Synchronization of Brain Responses during Natural Music Listening. *Eur. J. Neurosci.*, 37: 1458-1469.

Attanasio, A. (2010). *Darwinismo Morale. Da Darwin alle Neuroscienze*. Torino: Utet Università.

Chomsky, N. (1988). *Language and Problems of Knowledge*. Cambridge, Mass.: Mit Press.

Darwin, C. (1871). *The Descent of Man, and Selection in Relation to Sex*. Vol. 2. London: John Murray.

Darwin, C. (2010). *Taccuini Filosofici*, Transcription by Notebooks MMSS. Ital. Trans. Edited by A. Attanasio. Torino: Utet Università.

Darwin, C. (2011). *Capacità Mentali e Istinti negli Animali*. Ital. Trans. Edited by A. Attanasio. Torino: Utet Università.

Dawkins, R. (1976). *The Selfish Gene*. New York: Oxford University Press.

Deary, I. (2008). Why do Intelligent People Live Longer? *Nature*, 456: 175-176.

Dennett, D. (1978). *Brainstorms*. Cambridge Mass.: Bradford Books.

Editorial (2015). Rethinking the Brain. *Nature*, 519: 389.

Edelman, G.M. (1992). *Bright Air, Brilliant Fire. On the Matter of the Mind*. New York: Basic Books.

Edelman, G.M., & Tononi, G. (2000). *A Universe of Consciousness. How Matter Becomes Imagination.* New York, NY: Basic Books.

Edelman, G.M. (2004). *Wider Than The Sky. The Phenomenal Gift of Consciousness*. New Haven: Yale University Press.

Fodor, J. (1975). *The Language of Thought*. New York: Crowell.

Gelli, F., Del Santo, F., Mazzocchio, R., & Rossi, A. (2005). Force Estimation Processing as a Function of the Input–Output Relationship of the Corticospinal Pathway in Humans. *European Journal of Neuroscience*, 22: 1127-1134.

James, W. (1890). *Principles of Psycology*. London: MacMillan.

Hume, D. (1739-40). *A Treatise of Human Nature*. Edited by D.F. Norton and M.J. Norton. Oxford: Oxford University Press, 2000.

Panksepp, J. (1998). *Affective Neuroscience*. Oxford: Oxford University Press.

Panksepp, J. (2003). At the Interface between the Affective, Behavorial and Cognitive Neurosciences: Decoding the Emotional Feelings of the Brain. *Brain and Cognition*, 52: 4-14.

Pugh, G.E. (1977). *The Biological Origin of Human Values*. New York: Basic Books.

Putnam, H. (1981). *Reason, Truth and History*. Cambridge: Cambridge University Press.

Quine, W.O. (1953). *From A Logical Point of View*. Cambridge, MA: Harvard University Press.

Rossi, A., Rossi, S., & Ginanneschi, F. (2012). Activity-Dependent Changes in Intrinsic Excitability of Human Spinal Motoneurones Produced by Natural Activity. *J. Neurophysioly*, 108: 2473-2480.

Rossini, P.M., Rossi, S., Pasqualetti, P., & Tecchio, F. (1999). Corticospinal Excitability Modulation to Hand Muscles During Movement Imagery. *Cereb. Cortex*, 9: 161-167.

Russell, B. (1921). *The Analisys of Mind*. London: G. Allen & Unwin Ltd.

Santarnecchi, E., Polizzotto, N.R., Godone, M., Giovannelli, F., Feurra, M., Matzen, A., Rossi, A., & Rossi, S. (2013). Frequency-Dependent Enhancement of Fluid Intelligence Induced by Transcranial Oscillatory Potentials. *Current Biology*, 15:1449-53.

Santarnecchi, E., Galli, G., Rossi, A., & Rossi, S. (2014). Efficiency of Weak Brain Connections Support General Cognitive Functioning. *Human Brain Mapping*, 35:4566-4582.

Santarnecchi, E., D'Arista, S., Egiziano, E., Gardi, C., Petrosino, R., Vatti, G., Reda, M., & Rossi, A. (2014). Interaction between Neuroanatomical and Psychological Changes after Mindfulness-Based Training. *PLoS One*, 9 (10): e108359.

Santarnecchi, E., Rossi, S., & Rossi, A. (2015). The Smarter, the Stronger: Intelligence Level Correlates with Brain Resilience to Systematic Insults. *Cortex*, 64: 293-309.
Salimpoor, V.N. (2013). Interactions Between the Nucleus Accumbens and Auditory Cortices Predict Music Reward Value. *Science*, 6129: 216-9.
Searle, J.R. (1997). *The Mystery of Consciousness*. New York: The New York Review of Books.
Searle, J.R. (2004). *Mind. A Brief Introduction*, Oxford: Oxford University Press.
Seung, S. (2012). *Connectome*. Houghton: Mifflin Harcourt.