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Studi

The Distribution of Consciousness: A Difficult Cartesian Chart

Marcello Massimini[α],[β]

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Abstract If we were asked to draw a graph to represent the distribution of consciousness in the world around us (from dolphins to honeybees) based on objective criteria, we would definitely be in trouble. The two objective parameters that have been traditionally considered as a guide – the complexity of behavior and brain size – lead to paradoxical conclusions and turn out to be unsatisfactory, to say the least. We need to find novel, reliable metrics. However, these can be identified, validated and calibrated only if we first tackle seriously the problem of recognizing consciousness in our fellow humans, a task which is far from being obvious.

KEYWORDS: Consciousness; Animal; Brain; Behaviour; Coma

Riassunto *La distribuzione della coscienza: un difficile diagramma cartesiano* – Se ci chiedessero di tracciare un grafico per rappresentare la distribuzione della coscienza nel mondo che ci circonda (dai delfini alle api) su una base oggettiva, ci troveremmo sicuramente in difficoltà. I due criteri oggettivi che sono stati tradizionalmente presi in considerazione come guida – la complessità del comportamento e la dimensione del cervello – conducono a conclusioni paradossali rivelandosi, come minimo, insoddisfacenti. È necessario individuare altre misure. Ma queste potranno essere individuate, validate e calibrate soltanto se prima affronteremo seriamente il problema di riconoscere la coscienza nell'uomo, un compito tutt'altro che scontato.

PAROLE CHIAVE: Coscienza; Animale; Cervello; Comportamento; Coma

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Plotting a chart

IS SUBJECTIVE EXPERIENCE AN EXCLUSIVE privilege of humans or can the flame of consciousness burn elsewhere, in this wondrous world that surrounds us?

Let's try to transform this question into chart form. We will put all biological and nonbiological objects that populate the planet on the x-axis. We could put them in random order, but just for the sake of convenience we will sort them roughly into their reverse phylogenetic order: first come the humans, then the apes and the other terrestrial mammals,

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[α]Dipartimento di Scienze Mediche e Biochimiche "Luigi Sacco", Università Statale degli Studi di Milano, via Gian Battista Grassi, 74 - 20157 Milano (I)

[β]Istituto Di Ricovero e Cura a Carattere Scientifico, Fondazione Don Carlo Gnocchi, via Alfonso Capecelatro, 66 - 20148 Milano (I)

E-mail: marcello.massimini@unimi.it (✉)

then the marine mammals, the birds, the reptiles, the amphibians, the invertebrates, the mushrooms, the plants, bacteria and so on. We don't want to leave anything out, so we will add inanimate objects such as crystals, stones, human artefacts such as telephones, computers, GPS and so on. The intensity of primary consciousness goes onto the y-axis. What do we mean by primary consciousness?

The sensation we experience when watching the landscape passing by through the window of the train, when we are completely absorbed by the plot of a film, or remain captivated by the sound of the waves rippling onto the shore and the play of light on their crests. Anything that doesn't require a special effort of concentration, attention or memory, imagination or thought, planning or choice.

Only those who have practised meditation as a rigid discipline for years can truly say whether it is possible for a human being to shake of the weight of his actions, reflections, self-awareness, but what we can say with a satisfactory degree of certainty is that experiencing a colour, a flower, appreciating the purity of a sound, a perfume or enduring pain can occur without effort, or reflection, or self-awareness. It is a fact that without the flame of primary consciousness, it is not possible to burn the reflections and twisted blasts of self-consciousness. This then is the fundamental quantity we will put on the y-axis: the ability to have the simplest of experiences.

Once we have defined the variables of the axes, we can start with a few interesting questions. Let's start by asking how the capacity to feel pain, such as burning our fingertips, is distributed along our x-axis. Of course, we could have considered the experience of pleasure, or the perception of red or blue.

We chose pain as it is more effective in stressing the sense of ethical urgency related to the problem of the existence of consciousness in non-human beings. How do you think the chart will look? Will it have a peak against humans and then fall precipitously to zero in all the other categories? Or will it be a straight horizontal line, a constant across all categories? A trend which plunges suddenly at the divide between the animate and the inanimate worlds? A curve with a more gradual profile? Or maybe none of these, but an unexpected zigzag? Well, at present we just don't know for certain. What we can say is that whatever the replies we give to these questions, they will condition the way we interact with the other inhabitants and objects that populate our planet.

In 1974 the American philosopher Thomas Nagel asked the question *What is it like to be a bat?,*[1] with the aim of throwing light on the issue of privacy and inviolability of subjective experience. It has become a classic in philosophy. We will probably never know what it feels like to explore the intricate depths of a wood winging through branches with only sonar to guide us, but the real problem is that we will never know if there is such a feeling as feeling something as a bat. In fact, we do not have a clear and shared idea of how consciousness is distributed throughout the objects in the world, including animals.

The basic issue is of course that they don't speak, or more precisely, that they do not use a language to which we are privy. Since we are accustomed to attribute consciousness to beings that speak and communicate their feelings, we are immediately at a disadvantage when faced with the absence of a language that we can decode. Thus, opinions may vary extremely depending on whom you ask and this uncertainty has remained unchanged over the centuries. See, for example, the radical divergence between the ideas expressed by two great French philosophers, Descartes and Montaigne.

Descartes drew a sharp line between humans and the rest of the natural world. According to the father of the *cogito ergo sum*, verbal and non-verbal language and logical reasoning are the distinguishing factors that separate man from all the other species. Flourishing the principle of parsimony (Occam's razor), which holds that it is useless to look for more explanations than are strictly necessary to describe a given phenomenon, the French philosopher maintained that the behaviour of all non-human animals can be explained without calling consciousness into play.

According to Descartes, animals do not communicate their thoughts, therefore their actions, however surprising and complex they may seem, are to be interpreted in purely mechanical terms. Just like the machines produced by mankind, animals are machines produced by Nature. In his *Discourse on Method*, Descartes concluded that animals are just mechanisms that are incapable of any feeling whatsoever:

> It is Nature which acts in them, according to the disposition of their organs. Similarly, people recognize that a clock, which is composed only of wheels and springs, can count the hours and measure time more accurately than we can with all our practical wisdom.[2]

Descartes was the first to perfect the system of orthogonal axes (x, y), which still carries his name today. Then, how would he have drawn the chart plotting primary consciousness (y-axis) versus the objects of the world (x-axis)?

Most probably Descartes' plot would have been extremely simple: a gigantic peak for humans that fell back to zero as soon as his pen moved along the x axis towards non-human primates and a straight line from there down to the stones, without even the smallest blip along the way. Very neat and tidy, but how would Descartes have classified those millions of patients who lie motionless in the neurological wards and rehabilitation centres, human beings endowed with consciousness who have lost the power of speech and, sometimes, of reason.

And where would he have positioned those who have not yet acquired the capacity to use speech to communicate? On which side of the imaginary barrier would he have placed children who have not yet learned how to communicate their thoughts?

According to Descartes a 12 month old child who walks and plays in reality does not see and hear, but only behaves as if he sees and hears. Then a few months later this same child, after acquiring the faculty of language that allows him to communicate with his elders and peers, is suddenly the proud owner of consciousness, his world is populated with colour, forms, sounds, joys and sorrows. Is this plausible?

These are just a few of the problems that arise if, like Descartes, we decide to draw a sharp line between the conscious and the unconscious world. Just a few years earlier and very close geographically speaking, Michel de Montaigne formulated a position diametrically opposed to Descartes. A strong advocate of doubt and cultural relativism Montaigne loathed clear-cut distinctions and directly opposing positions, far preferring scepticism. He dealt with the question of the distribution of consciousness in nature and characteristically left all the possibilities open:

> When I play with my cat, how do I know that she is not passing time with me rather than I with her? […] Why should it be a defect in the beasts and not in us that which stops all communication between us? We can only guess whose fault it is that we cannot understand each other: for we do not understand them any more than they understand us. They may reckon us to be brute beasts for the same reasons as that we reckon them to be so.[3]

But this caution is only apparent! In reality, Montaigne sustained a position that in spite of being based on rather superficial elements was by no means less extreme than that held by Descartes:

> There is a greater difference between a man and another man than between an animal and a man.[4]

So, faced with our chart, the prudent French humanist would have conceded a comparable level of consciousness to every-one, men and animals alike (and maybe to the vegetable world for good measure). Montaigne, with his ecumenical approach that embraced the concept of consciousness for all living organisms including ants and spiders, enjoys a certain following today.

Take Peter Singer, for example, a contemporary Australian philosopher and animal activist pioneer, who draws the line between prawns and oysters (and mussels), for the delight of the palates of the better-off. Other contemporary thinkers have gone a step further, sustaining the view that consciousness is a property that is shared by single cells. The problem here is that if you see consciousness everywhere, is tantamount to not seeing it anywhere. If we follow this perspective, any decision that we take regarding the delicate equilibrium that exists between the interests of humans and of the other elements that populate the earth, would be totally arbitrary, would beg the issue and would probably be unjust in one way or another.

The objective of this brief digression into history, which is obviously incomplete, is just to give an idea of the range of possible positions regarding how consciousness is distributed in nature. It is certainly worthy of note that the range is just as wide today as it was in the times of Montaigne and Descartes. If you ask for an informal view, most people will say that for them inanimate objects are not conscious, and only some living beings are endowed with consciousness. Very few people think that bacteria, mushrooms or plants have any form of consciousness, and worms and leaches don't fare much better.

The debate becomes more heated when the subject matter moves up the scale to fish, amphibians and reptiles and can become ferocious when birds and mammals are discussed. It is unthinkable that the owner of a cat or a horse questions the capacity of these animals to perceive pain, while a dog owner feels that he cohabits with a particularly empathic being that feels, processes, remembers and understands. On the other hand there are those who maintain that there is no evidence of subjective experience in the animal kingdom, with the exception of man and (maybe) the great primates. There are even scientists who deny that the great non-human primates suffer pain.

To summarise, if we were to conduct a survey among representatives of the human race from different cultures, social extraction and religion, and asked them to draw the line on our chart of the distribution of primary consciousness, we would end up with innumerable different versions, with curves of varying form. The reason for this lack of consensus is perfectly clear: until we have a fundamental principle on which to recognise and if possible measure the presence of primary consciousness in matter, we are obliged to reason by analogy or even worse, on the basis of our personal feelings and inclinations. Which objective criteria should we adopt to recognise the presence of "someone who feels something" in a world populated by an incredible variety of beings that are not in a position to communicate their experiences to us.

The best way to start seems to be to analyse two aspects that can be observed without particular difficulty: the complexity of behaviour and the dimension of the brain.

Consciousness and behavior

It is perfectly reasonable to hypothesise a connection between the capacity to produce complex behaviour and the presence of consciousness; indeed there are a number of factors that sustain this intuition. In the first place, there is the simple fact that our capacity to interact significantly with the world around us decreases when the level of consciousness diminishes during sleep or when we are under the effect of an anesthetic.

Many scholars rightly hold that within certain limits the observation of behaviour can provide indicators of the presence of consciousness in the animal kingdom.[5] It is a fact that the more we observe animals, the greater the variety and complexity of behaviour that we perceive and this is not only true for primates, who are genetically closer to us, but also for animals that are phylogenetically far removed from the human species, such as dolphins, crows, parrots, octopi and bees. There is little doubt that these animals, aliens who live in bodies and eco-systems so different from ours, constitute the most interesting challenge of all so we will start by examining their behaviour patterns, moving from left to right on the x-axis of our hypothetical chart and descending the scale to reach the great divide between animate and inanimate beings.

Let's start with the dolphins. There is a wealth of scientific and literary literature on the behaviour of these animals. Whoever has visited a dolphin house will have been able to form an opinion of the capacity of these marine mammals to understand complex verbal instructions, to imitate, learn elaborate motor sequences and work out creative solutions. But what is more surprising and has greatly impressed scientists who have systematically studied dolphin behaviour is the complexity of their social interactions when they are in their natural habitat.[6]

These mammals seem to be particularly attentive to social dynamics; indeed, they seem to be almost obsessed with them. They live at an exhausting rhythm, weaving relationships, creating alliances, shifting alliances and betraying their allies. Dolphins see very little with their eyes, they use echo-localization instead, in much the same way as bats do. Not only do they monitor the area in which they are swimming, they also eavesdrop the return of the impulses emitted by other dolphins, to get an idea of what they are seeing. Marine biologists are coming to the conclusion that behind what appears to us to be a playful and happy-go-lucky existence, dolphins are actually involved in a social whirl that is far more intricate and paranoid than many human associations.

It seems that dolphins, like humans and the great apes, can recognise themselves in a mirror, which is a behaviour that many psychologists consider to be the behavioural correlate of the presence of consciousness. That said, it is extremely difficult to interpret the behaviour in front of a mirror of a dolphin, a being without hands or facial mimics, much more difficult than, say, interpreting that of a monkey. This is one of the reasons that the question of self-awareness in dolphins is still a subject of debate[7]. On the other hand, the most articulate behaviour is not necessarily the most indicative: sometimes dolphins blow bubbles, then they move off a little distance and turn to watch them dancing up through the water. Why do they do this? A moment of relax, a breath of fresh primary consciousness? Unfortunately dolphins cannot talk to us and so we just don't know.

But there are other animals who do talk to us. Parrots, for example. Take the case of Alex, an African Grey who was trained over a period of approximately thirty years by the American researcher Irene Pepperberg.[8] Towards the end of his life, Alex had acquired a vocabulary of one hundred and fifty words (similar to the vocabulary of a human two-year old), he could count up to six, distinguish seven colours and six geometric forms and had even a grasp of some general concepts such as "bigger", "smaller", "same", "different", "above", "below", and "zero".

He was able to categorize objects, like keys, independently of their colour, material or form, and when he was tired, he would say, "wanna go back", which certainly gave the lie to the common saying, "learn like a parrot". Alex died unexpectedly in 2007 and his successors have not revealed the same level of ability. Now, what would Descartes have said if he had been able to meet Alex?

Other birds don't speak, but show behaviour that we consider to be typically human, such as the ability to make and use utensils. The crows of New Caledonia, for example, have been known to bend a hair pin to make a hook that they use to extract food from a cylindrical container.[9] This type of activity reveals a noteworthy capacity for discrimination and planning. Another particularly interesting research study in 1995 assessed the ability of certain pigeons to recognise and distinguish the works of Picasso and Monet; after training they were able to distinguish paintings by these artists, even if they had never seen the paintings before.

Going further down our scale, we come to the octopus, a marine mollusc with eight limbs and three hearts that would not look out of place in a far-fetched science fiction film. Is it really worthwhile investigating the consciousness of this cephalopod that lives a solitary existence among the rocks on the sea bed?

The answer of course is yes. The octopus' behaviour indicates that it is no less worthy of attention than the vertebrates. Octopus vulgaris has a range of extraordinarily flexible behaviours, supported by a significant working memory and a highly developed power of concentration.[10] It is able to distinguish artefacts of different weights, forms and dimensions, it uses objects such as stones and the shell of the coconut to procure food, to hide, to play, and is able to learn the best strategy (among many) to find a way out of a maze. Although octopi are not social beings, they have an extraordinary capacity to learn from other octopi: one particular octopus in an aquarium observed its neighbour opening a jar to extract food, and immediately imitated the same movements as soon as it was given a similar jar. Given these abilities, and other factors, the octopus has been the subject of UK and EU protective legislation "as there is scientific evidence of their ability to experience pain, suffering distress and lasting harm".

Moving further down the scale we come across a swarm of bees. The social behaviour of these insects, (division of labour, construction and maintenance of the beehive, castes and task differentiation depending on age) is notoriously complex, even though less flexible than that of the dolphins. Recent studies have in fact demonstrated that many of the aspects of the bees' social behaviour are somewhat rigid as they are genetically predetermined. This doesn't change the fact that bees have incredible abilities, such as that of communicating distances and coordinates of food sources to other bees with extreme precision.[11]

This communication is done by a figure 8 "waggle dance", during which the bee performs waggling movements. Flowers located in line with the sun are indicated by a waggling run in an upward direction and any angle to the right or the left of the sun is coded with a corresponding angle to the right or the left of the upward direction. The distance between the hive and the recruitment target is encoded in the duration of the waggle runs. The further away the food source, the longer the waggle, with an increase coefficient of approximately 75 milliseconds for every 100 meters. Apparently more expert bees, the ones who have been in the hive longest, are even capable of adjusting the angulation of their waggle dance to take into consideration the movement of the sun, so that the additional help is able to find the food source immediately. This is a really extraordinary achievement in a tiny object that weighs less than the tenth of a gram.

This quick tour de force from dolphins to bees seems to suggest that, based on behaviour's complexity, some form of primary consciousness could be present all along. But now the time has come to move further to the right along the x-axis and to cross the divide between the animate and the inanimate. First of all, let us consider a GPS. Listen to that persuasive voice telling you which is the best route to the restaurant with greater precision than your partner does. And what about your laptop that never fails to beat you at chess? Not to mention those supercomputers such as Watson that can answer any question.

There can be no doubt that these gadgets, that can produce language and calculations, would have given Descartes food for thought. Just imagine if he had met Alex the African Grey parrot and then encountered the supercomputer Deep Blue playing chess with Kasparov. At the very least he would have been in a quandary, as his theory basically stated that the power to speak and calculate was an indication of the presence of consciousness. In spite of this, we are in no doubt that our GPS, our laptop and Deep Blue are less endowed with consciousness than a parrot, an octopus or a bee. We would rate them zero in our chart, just as we would rate headphones, calculators and lawnmowers. But hold on a minute! Why are we so certain? Just because we know that these are all human artefacts?

Indeed this is the answer; we agree that these articles are unconscious because we know that their impressive performance is due to speed of calculation and the respect of a series of rules that we ourselves have imposed. But who is there to say that this might not be the case for many animals who show complex behaviour that are dictated by genetic rules?

This is the problem with the consciousness/behaviour relation: however appealing it may be, the mere fact that a behaviour repertoire is complex is not sufficient to clinch the case for the presence of consciousness. Indeed, it isn't even a necessary condition. It would be a grave error to deny consciousness to a patient lying paralyzed in a hospital ward, or to a man happily dreaming; it is probably an error to deny it to a dolphin that has opted to pass its existence watching bubbles of air rising through the water. It is thus fair to conclude that assessing consciousness through behaviour is a risky choice.

Consciousness and brain size

So much for behaviour, but what about the other objective criteria that we can easily observe and measure, the size of the brain? It would seem inevitable that there should be some form of relation between the dimension of the brain and the level of consciousness.

We know that in humans lesions that involve large areas of the brain cause a reduction or even the total loss of consciousness, and that this damage is frequently irreversible. We are so sure of the general value of this, that we identify the death of an individual with the death of all (or almost all) of his neurons, so it is worthwhile reflecting for a moment on the relationship between the quantity of neurons and the quantity of consciousness in the inhabitants of the biological universe, particularly as the dimension of the brain can be measured accurately.[12]

A brain size-based graph, would see the seven kilos of sperm whale's brain at the top of the scale, while at the bottom we would find the hamster with his one gram brain and the bees, an order of magnitude below. In between there is the elephant with a respectable five kilo brain, the dolphin with one and a half kilos, humans just below the dolphins at fourteen hundred grams, monkeys at four hundred grams, dogs with eighty grams and parrots with 6 grams. These values are hardly indicative of the extent of the cognitive faculties, however.

The dimension and weight of a brain primarily depend on the dimension and weight of the animal; larger animals need more and larger neurons, to control the basic functions of the host. An elephant will need many more receptors, sensitive neurons and motor neurons to control its immense surface (an elephant's skin can reach 100 thousand sq. centimetres in size) and muscle mass (the trunk alone contains up to 100,000 muscles) than a hamster. Therefore before we start thinking about the brain's dimensions in relation to cognitive functions, one ought to correct for the creature's size.

Neuro-anatomy has solved this issue by using an index, known as the Encephalization Quotient (EQ)[13] which is an approximate measure of relative brain size as defined by the ration between the actual brain mass and the predicted brain mass of a given animal. In general, in mammals the dimension of the neural system increases as the size of the animal increases, following an exponential curve (with a power of approximately 0.66). Some species are collocated below this average curve and others above; the EQ quantifies the deviation from the average.

The idea is that the excess neurons, the ones that are not strictly necessary to regulate the somatic base functions, can be dedicated to the superior cognitive functions. In fact, when the EQ is adopted as the criteria rather than the simple weight of the brain, the ranking of brain size changes quite significantly. Humans shoot to the top with an EQ ration of 6.5, followed by dolphins (5.5), chimpanzees (2.6), elephants (1.8), dogs (1.2), parrots (1), hamsters (0.6) and last (and in this case least) the sperm whale with 0.26. However this system of measurement has its limits; it is only applicable to mammals, tends to penalise larger animals and does not take the number of neurons into consideration, which of course is a more important factor that the weight per se. All the same, it does provide a scale which is more acceptable than that of just the mere weight of the cerebral mass. So can we use it to form an idea, quantitative-wise, of the level of consciousness in the animal kingdom? It appears not.

In fact, it is enough to consider a fundamental paradox that lies within our skulls. The head of a typical human being houses approximately 100 billion neurons in two distinct structures: the thalamocortical system and the cerebellum. The former, which is composed of the cerebral cortex and the thalamus, takes up most of the available space, while the latter is tucked away in the posterior cranial fossa, which is more or less at the level of the nape of the neck. It is surprising that this relatively small structure, which is extremely elegant and compact, contains the majority of the neurons. In fact the cerebellum is home to 80 billion neurons (neatly packed-in) while the thalamocortical system, including the brain stem, has only 20 billion.

As is to be expected, the cerebellum is rich in resources. Its communication network is just as vast and sophisticated as that of rest of the brain, it contains the same cocktail of chemical substances and copes with an intense exchange of information with the external world through the sensory and motor organs. It receives visual, acoustic, tactile and various other signals, and emits motor commands that regulate many aspects of our behaviour. When all is said and done, it is a marvel of biological intricacy. The paradox is that the cerebellum, even with its dense neuron population, has very little to do with consciousness. There are certain tumours which can invade the cerebellum rapidly, with the risk that they could spread to the rest of the brain. In such cases, the only option is to perform a very radical surgery, and remove the cerebellum. During this operation, the cerebellum with its 80 billion neurons is completely lifted from the cranium and dumped in the surgical waste disposal unit. What are the consequences of such a drastic manipulation in humans?

An individual without a cerebellum is easily identifiable by the way he walks, with legs wide apart, gingerly and clumsily. He has difficulty in coordinating rapid movements, he shakes and tends to articulate words syllable by syllable, sometimes in an explosive manner. Although such individuals have obvious difficulty in coordinating their movements, their consciousness is surprisingly unaffected.[14] In fact, conscious experience in these patients remains as vivid and intense as before; forms, colours, sounds, smells, tastes, emotions, thoughts and pain, the extraordinary variety of consciousness survives intact. In essence, the cerebellum contains 80% of the neurons that inhabit our cranium, but does not perceive light or darkness, it cannot see colours or feel pain and would score zero on the y-axis of the graph we are attempting to draw. In stark contrast, we know far too well that even a partial lesion of the remaining 20% of neurons, the ones that make up the cerebral cortex and the thalamus, may abolish consciousness altogether; patients with severe lesions to these neurons plunge into coma, or the vegetative state. The simple fact that the thalamocortical system generates consciousness and the cerebellum does not, is a fundamental mystery that should throw light on the biological basis of consciousness. For now this fact tells us that counting neurons, let alone measuring brain size, will not say much about the presence or absence of consciousness. Are the 20 billion neurons that run the elephant's brain more or less conscious than the 80 billion neurons of our cerebellum? Which are more effective, the 160 million neurons in the brain of a dog, or the 300 million that the octopus possesses?

Apart from some organizational aspects that are common to most beings, neural cells and their connections form different architectures from one animal to another. The human nervous system is different from that of a dolphin, which is very different from that of a parrot that has nothing in common with the nervous system of a fish.[15] The octopus is a case apart, at least two thirds of its neurons are decentralized in its tentacles.

Are the octopus's 300 million neurons similar to the ones of our cerebellum with respect to consciousness or are they closer to the ones of our cerebral cortex? Can one throw the cephalopod into the cooking pot with just the same lack of qualms that the neuro-surgeon throws the diseased cerebellum into the operating theatre's refuse?

Difficult to say, at this stage. After all, it will be impossible to infer an octopus' consciousness at the bottom of the sea if we cannot solve the basic mystery of the cerebellum, which is in the back our own cranium.

First of all, consciousness in humans

Indeed, the real and most urgent problem is that we still lack a reliable method of detecting consciousness in our fellow humans. Though we are very familiar, via a first-person perspective, with the transition from consciousness to unconsciousness and back, we still lack a scientifically well-grounded method to assess the level of consciousness of other individuals. How do we judge if another human is conscious – experiencing things such as sights, sounds, and maybe pains?

Usually, if we observe purposeful behavior and appropriate responses to sensory stimuli or commands, we decide that the person is conscious. If in doubt, as when someone is resting with eyes closed, we can ask: if she answers that she was thinking or daydreaming, we infer she was conscious. But sometimes matters are less clear: someone fast asleep shows no purposeful activity and will not respond to questions. If awakened, at times she may say she was experiencing nothing; at other times that she was dreaming, and recalls a vivid experience. The matter becomes even more complicated in patients who suffered severe brain injuries. The bedside evaluation of these subjects relies on repeated behavioural observation by trained personnel. During the examination, spontaneous and elicited behaviour in response to multisensory stimulation is recorded in accordance with specific scales.[16]

Regardless of the scale employed, the examiner typically looks for (1) evidence of awareness of the self or of the environment, (2) evidence of sustained, reproducible, purposeful or voluntary response to tactile, auditory or noxious stimuli and (3) evidence of language comprehension and expression. If none of these three defining behavioural features can be detected during careful and repeated evaluations, the subject is considered unconscious, while patients who show non-reflexive behaviour but are unable to communicate their thoughts and feelings are ascribed to a recently defined clinical entity, the minimally conscious state.[17]

Thus, according to the clinical definition of consciousness, subjects are conscious, or minimally conscious, to the extent that they can signal that this is the case. However, since in patients with severe brain injury motor responsiveness is often impaired, it may also happen that a subject is aware but unable to move or speak.[18] In this case, looking at motor behaviour would not say much. An additional problem is that conscious experience can also be present in subjects who are disconnected from the environment on the input side. For example, during dreaming complex, temporally unfolding hallucinatory episodes can be as intense and vivid as waking consciousness – yet sensory stimuli are ignored to the point that they are rarely incorporated in the experience.[19]

Consciousness may completely disconnect from the external environment also during some forms of anesthesia. Some dissociative anesthetic agents, such as ketamine at high doses, are known to induce a dreamlike hallucinatory state associated with sensory disconnection and complete unresponsiveness[20]. Similar disconnections may occur in pathological conditions whereby a brain-injured subject may not respond to verbal commands or sensory stimuli because a peripheral or central lesion prevents sensory inputs from being transmitted and processed effectively. In all these cases, detecting consciousness based on a behavioural paradigm may result in a significant rate of false negatives. In fact, it is estimated that about 40% of minimally conscious patients are erroneously considered unconscious and thus labelled as being in a vegetative state.[21]

Today, intensive care medicine saves thousands of brain-injured patients from certain death. Some of them will recover their ability to interact with the environment and communicate that they are conscious, but others will not. How does it feel to be an isolated chunk of cerebral cortex in a sea of devastation? Is it nothingness like deep sleep or general anesthesia? Is it nothingness like being a cerebellum? Is it a disconnected dreamlike state? Is it painful?

It would seem that before looking for consciousness in the deep of the sea, behind the words of a parrot or in a buzzing beehive, we should learn to detect consciousness at the bedside of our fellow humans. This is not only an ethical obligation but also the first necessary step if we want to be able, one day, to detect consciousness among the many brains populating our planet.

First steps towards an objective index of consciousness

Whether it will be possible to develop a universal consciousness-meter to carry around the planet is difficult to say. One thing is certain: whatever metric we develop, it will need to be calibrated in humans first. When it comes to consciousness, the only control of the true state of affairs is somebody else's explicit report, or even better our own experience. Take any candidate general brain-based measure of consciousness – let's say, for instance the level of activity of a particular group of neurons, or an index of global neural synchrony – and let's call it M. How do we validate this measurement?

There is only one way; to see how this measurement varies when our own experience changes, fades and recovers. In practice, one has to validate M across several physiological, pharmacological and pathological conditions on himself first and then in a large cohort of fellow humans who are able to provide an immediate (or retrospective) report about their subjective experience. This validation should start from typical conditions in which consciousness is present (wakefulness) or lost (deep non rapid eye movement – NREM – sleep, seizures, anesthesia) and shall then extend to more ambiguous cases in which consciousness may be present albeit disconnected (dreaming, ketamine anesthesia).

To the extent that this long process yields an index that is highly specific and highly sensitive for the presence of an immediate, or retrospective, conscious report across all these conditions, one may move forward; at this point, M should be validated in brain injured patients, thus making sure that it is sensitive to the presence of consciousness in challenging cases, including patients in whom only some islands of brain tissue are preserved and who are able to provide only minimal signs of consciousness. In essence, the goal is to be able to calibrate M on a y-axis along the spectrum from consciousness to unconsciousness in humans who retain some (even minimal) form of communication. Then, one shall apply the same measurement to brains that are unable to interact and communicate, and just trust it. If in a non-communicating patient who is considered vegetative, M is as high as in a subject who reports experience, then one should conclude that this patient has a covert capacity for consciousness.

Finally, we shall apply the same logic to other kinds of brain, such as the one of a parrot or of an octopus. It may sound exotic and risky, but is it more hazardous than relying on behaviour or number of neurons? Can we think of anything better?

Recently, we have attempted to go in this direction by (1) devising a theory-based candidate index of consciousness (2) validating it in a benchmark population of communicative subjects and (3) applying it to comatose patients.

The first step required identifying a metric that captures, among the many possible variables that can be empirically measured from the brain (levels of neuronal activity, levels of synchronization, and the like), the one that – at least in principle – may be relevant for consciousness. A parsimonious approach is to start from self-evident axioms in order to establish what physical properties are fundamental for consciousness and how they can be measured. Naturally, in the case of consciousness, evidence can only be gathered from phenomenology, the first-person observation of subjective experience itself. Phenomenologically, each conscious experience is both differentiated – that is, it has many specific features that distinguish it from a large repertoire of other experiences – and integrated – that is, it cannot be divided into independent components. Neurophysiologically, these fundamental properties of subjective experience rely on the ability of multiple, functionally specialized modules of the thalamocortical system to interact rapidly and effectively to form an integrated whole. Hence, the fundamental postulate is that consciousness requires an optimal balance between functional integration and functional differentiation in thalamocortical networks-otherwise defined as brain complexity.[22] This notion implies that the complexity of brain activity should be high when consciousness is present and low whenever consciousness is lost in sleep, anesthesia, or coma.

A viable and principled way to gauge the conjoint presence of integration and information in real brains involves directly probing the cerebral cortex (in order to avoid possible subcortical filtering and gating) by employing a perturbational approach (thus testing causal interactions rather than temporal correlations) and examining to what extent cortical regions can interact as a whole (integration) to produce differentiated responses (information).[23] Practically, this approach can be applied to the human brain by employing a combination of transcranial magnetic stimulation (TMS) and high-density EEG, a technique that allows stimulating directly a subset of cortical neurons and measuring, with good spatial-temporal resolution, the effects produced by this perturbation on the rest of the thalamocortical system. According to this proposal, a signature of consciousness is that the thalamocortical system should respond to TMS with complex, rapidly changing activity patterns (information) that affect a distributed set of cortical areas (integration). On the other hand, it can be predicted that during loss of consciousness, whether this is caused by sleep, anesthesia, or coma, the brain should react to perturbations with a response that is local (loss of integration) and/or stereotypical (loss of information). In order to quantify the spatiotemporal complexity of TMS-evoked cortical activations, a novel empirical measure called the perturbational complexity index (PCI) has been recently introduced. Calculating PCI involves two fundamental steps: (1) perturbing the cortex with TMS to engage distributed interactions in the brain (integration) and (2) "zipping" (i.e., compressing) the resulting electrocortical responses to measure their algorithmic complexity (information). The underlying idea is that PCI should be low if causal interaction among cortical areas is reduced (loss of integration), because the matrix of activation engaged by TMS is spatially restricted; PCI is also expected to be low if many interacting areas react to the perturbation but they do so in a stereotypical way (loss of differentiation) because, in this case, the resulting matrix is large but redundant and can be effectively compressed. In fact, PCI should reach high values only if the initial perturbation is transmitted to a large set of integrated areas that react in a differentiated way, giving rise to a spatiotemporal pattern of deterministic activation that cannot be easily reduced.

For, now there is encouraging evidence that measuring neural complexity with PCI reliably detects consciousness in humans independent of behaviour and extent of brain lesion (or residual brain size). Empirically, this measure of brain complexity establishes a common measurement scale that is valid across many different conditions along the unconsciousness/consciousness spectrum and reliable at the level of single individuals including subjects who are awake and able to report immediately that they are conscious, subjects in REM sleep[24] and under ketamine anesthesia[25] who are unresponsive but able to report retrospectively that they were conscious, subjects in NREM[26] sleep or general anesthesia (midazolam, propofol and xenon) who provide no conscious report upon awakening, unresponsive wakefulness syndrome/ vegetative state patient, and responsive brain-injured patients who are in a minimally conscious state, or in a locked-in syndrome (LIS).[27] Being validated in these conditions, PCI is now ready to be applied to unresponsive patients; specifically, given the accuracy of PCI in the benchmark population, one should assume that finding high brain complexity in a patient who is behaviourally vegetative indicates the presence of covert consciousness, above and beyond communication and behaviour. These measurements only represent a first attempt, they may be invalidated by the next experiments and must be substantially improved.

Whether some theoretically-inspired and technically-refined measure of neural complexity will help us drawing a sensible graph of the distribution of consciousness in the world around us is a question that is far to early to even ask. What is certain is that problem must be solved in humans first and that we need to be extremely careful, as many important decisions will depend on the unit we choose to assign to the y-axis of this fateful chart.

Notes

[1] See T. NAGEL, *What is it like to be a Bat?*, in: «The Philosophical Review», vol. LXXXIII, n. 4, 1974, pp. 435-450.

[2] R. DESCARTES, *Discours de la méthode*, Leiden 1637, p. 58 (En. tr. *Discourse on the Method*, in: J. COTTINGHAM, R. STOOTHOFF, D. MURDOCH (eds.), *The Philosophical Writings of Descartes*, vol. I, Cambridge University Press, Cambridge 1985, pp. 111-151, here p. 140).

[3] M. MONTAIGNE, *Apologie de Raymond Sebond* (1580), in: M. MONTAIGNE, *Essais*, Livre 2, édition établie par P. MICHEL, Gallimard, Paris 1965, pp. 138-351, cit. p. 156 (En. tr. *An Apology of Raymond Sebond*, in: M. MONTAIGNE, *The Complete Essays*, edited by M.A. SCREECH, Penguin Books, London 2003, pp. 595-781, here p. 611).

[4] *Ivi*, p. 173 (En. tr. p. 626).

[5] Cf. D.B. EDELMAN, B.J. BAARS, A.K. SETH, *Identifying Hallmarks of Consciousness in Non-mammalian Species,* in: «Consciousness and Cognition», vol. XIV, n. 1, 2005, pp. 169-187.

[6] Cf. D. REISS, B. MCCOWAN, L. MARINO, *Communicative and Other Cognitive Characteristics of Bottlenose Dophins*, in: «Trends in Cognitive Science», vol. I, n. 4, 1997, pp. 140-145.

[7] Cf. D. REISS, L. MARINO, *Mirror Self-recognition in the Bottlenose Dolphin: A Case Of Cognitive Convergence*, in: «Proceedings of the National Academy of Sciences USA », vol. XCVIII, 2001, pp. 5937-5942.

[8] Cf. I.M. PEPPERBERG, *In Search of King's Solomons Ring: Cognitive and Communicative Studies of Grey Parrots*, in: «Brain Behavior and Evolution», vol. XLIX, n. 1-2, 2002, pp. 54-67.

[9] Cf. N.J. EMERY, N.S. CLAYTON, *The Mentality of Crows: Convergent Evolution of Intelligence in Corvids and Apes*, in: « Science», vol. CCCVI, n. 5703, 2004, pp. 1903-1907.

[10] Cf. J.A. MATHER, *Cephalopod Consciousness: Behavioural Evidence*, in: «Consciousness and Cognition», vol. XVII, n. 1, 2008, pp. 37-48.

[11] Cf. F.C. DYER, *The Biology of the Dance Language*, in: «Annual Review of Entomology», vol. XLVII, 2002, pp. 917-949.

[12] Cf. O. CAIRÒ, *External Measures of Cognition*, in: «Frontiers in Human Neuroscience», vol. V,

2011, Art. Nr. 108.

[13] Cf. H.J. Jerison, *The Theory of Encephalization*, in: «Annual of the New York Academy of Sciences», vol. CCXCIX, 1977, pp. 146-160.

[14] Cf. R.N.Lemon, S.A. Edgley, *Life without a Cerebellum*, in: «Brain», vol. CXXXIII, Pt. 3, 2010, pp. 652-654.

[15] Cf. A.B. Butler, *Evolutions of Brains, Cognition and Consciousness*, in: «Brain Research Bulletin», vol. LXXV, n. 2-4, 2008, pp. 442-449.

[16] Cf. J.T. Giacino, K. Kalmar, J. Whyte, *The JFK Coma Recovery Scale Revised: Measurements Characteristics and Diagnostic Utility*, in: «Archives of Physical Medicine and Rehabilitation», vol. LXXXV, n. 12, 2004, pp. 2020-2029.

[17] Cf. J.T. Giacino, S. Ashwal, N. Childs, R. Cranford, B. Jennett, D.I. Katz, J.P. Kelly, J.H. Rosenberg, J. Whyte, R.D. Zafonte, N.D. Zasler, *The Minimally Conscious State: Definition and Diagnostic Criteria*, in: «Neurology», vol. LVIII, n. 3, 2002, pp. 349-353.

[18] Cf. C. Schakers, S. Majerus, S. Goldman, M. Boly, P. Van Eeckhout, S. Gay, F. Pellas, V. Bartsch, P. Peigneux, G. Moonen, S. Laureys, *Cognitive Function in the Locked-in Syndrome*, in: «Journal of Neurology», vol. CCLV, n. 3, 2008, pp. 323-330.

[19] Cf. D. Koulack, *Effects of Somatosensory Stimulation on Dream Content*, in: «Archives of General Psychiatry», vol. XX, n. 6, 1969, pp. 718-725.

[20] B.B. Collier, *Ketamine and the Conscious Brain*, in: «Anesthesiology», vol. XXVII, n. 2, 1972, pp. 120-134.

[21] Cf. S. Majerus, H. Gill-Thwaites, K. Andrews, S. Laureys, *Behavioral Evaluation of Consciousness in Severe Brain Damage*, in: «Progress in Brain Research», vol. CL, 2008, pp. 397-413.

[22] Cf. G. Tononi, G. Edelman, *Consciousness and Complexity*, in: «Science», vol. CCLXXXII, n. 5395, 1998, pp. 1846-1851; G. Tononi, *An Information Integration Theory of Consciousness*, in: «BioMed Cental Neuroscience», vol. V, 2004, Art. Nr. 42.

[23] Cf. M. Massimini, M. Boly, A. Casali, M. Rosanova, G. Tononi, *A Perturbational Approach to for Evaluating the Brain's Capacity for Conscoiusness*, in: «Progress in Brain Research», vol. CXVII, 2009, pp. 201-214.

[24] Cf. M. Massimini, F. Ferrarelli, M. Murphy, R. Huber, B. Riedner, S. Casarotto, G. Tononi, *Cortical Reactivity and Effective Connectivity During REM Sleep in Humans*, in: «Cognitive Neuroscience», vol. I, n. 3, 2010, pp. 176-183.

[25] Cf. S. Sarasso, M. Boly, M. Napolitani, O. Gosseries, V. Charland-Verville, S. Casarotto, M. Rosanova, A.G. Casali, J.F. Brichant, P. Boveroux, S. Rex, G. Tononi, S. Laureys, M. Massimini, *Consciousness and Complexity During Unresponsiveness Induced by Propofol, Xenonand Ketamine*, in: «Current Biology», vol. XXV, n. 23, 2015, pp. 3099-3105.

[26] Cf. M. Massimini, F. Ferrarelli, R. Huber, S.K. Esser, H. Singh, G. Tononi, *Breakdown of Cortical Effective Connectivity During Sleep*, in: «Science», vol. CCCIX, n. 5744, 2005, pp. 2228-2232.

[27] Cf. A.G. Casali, O. Gosseries, M. Rosanova, M. Boly, S. Sarasso, K.R. Casali, S. Casarotto, M.A. Bruno, S. Laureys, G. Tononi, M. Massimini, *A Theoretically Based Index of Consciousness Independent of Sensory Processing and Behavior,* in: «Science Translational Medicine», vol. V, 2013, Art. Nr. 198.