Chapter 3

Presentation of the Brain–Mind Interface

Before examining the manner in which neuronal interfaces may directly connect the mind and cyberspace, it is necessary to first study what these neuronal networks represent and how they function in the central nervous system, which includes the brain and the spinal cord.

The Central Nervous System

The central nervous system consists of the brain and the spinal cord, which are situated in the skull and vertebrae respectively. Both have easily described main structures, though in each case, the fine substructures are exceedingly complex. They are both also formed of neurons, which are cells that store, process and transmit information through electrical and chemical signals. These neurons comprise a central body from which emanate a number of long fibrous branches consisting of one axon and a number of dendrites. They are therefore spider-like with spindly filament extensions that branch out, repeatedly, to make contact with other parts of the same neuron or with other neurons. A network is thus formed of neuronal connections. All the nerves in the human body consist of a bundle of axons of many neurons conveying information to and from the central nervous system.

Glial cells are also present in the nervous system and act to support neurons by enabling important chemical and physiological reactions to take place producing a number of substances required for normal neurological functioning.

Information in the nervous system is coded as electrical-chemical messages and sent through chains of neurons, usually going in one direction, from the dendrites through the cell body and along the axon, which is then connected to a dendrite or cell body of a neighbouring neuron.

The very small interconnecting gaps between neurons are called synapses and occur at the point where one neuron touches another, and are the places where signals are transferred. When a neuron transmits a message to a neighbour, it initiates an electrical signal to the synapse, eliciting the release of a small package of chemicals. These chemicals travel across the microscopic gap between the two cells, triggering a shock wave through a pulse of voltage in the second neuron, which then moves down its extensions. The nature of the response depends on the types of cells and the types of chemicals released.

Neurons are usually specialised in different ways in order to fulfil specific tasks. The number, length and pattern of the extensions that develop from the cell, the connections these make with other neurons, the neurotransmitters that are released to the neighbouring cell and the surface channels of receptors all make a neuron very specific in its role.[1] This form of organisation of the neurons is the basis of a kind of regional specialisation of function and is believed to increase the speed of communication.[2]

The brain makes up the largest portion, is the major functional unit and is often referred to as the main structure of the central nervous system. The spinal cord, on the other hand, has certain processing abilities relating to, for example, spinal locomotion and process reflexes.

The Spinal Cord

The spinal cord is the main pathway supporting information between the brain and the peripheral nervous system. Extending from the base of the brainstem is a bundle of neurons making up nerve fibres reaching down through a protective channel in a person's spinal column. It is a major trunk route directing signals from the brain to the body and vice versa.

However, it would be a mistake to see the spinal cord as a passive conduit of information. Much of the basic functional control of a person's body is organised within the spinal cord protected by the bony spinal column, with a length of about 45 cm in men and 43 cm in women, made up of bones called vertebrae. Although the spinal column is somewhat flexible, some of the vertebrae in the lower parts of the column may become fused.

The Brain

The brain is the most complex organ in the human body and is protected by the skull against any outside interference other than the neurons in the spinal cord and the brainstem, as well as hormonal changes in the blood supply.[3]

It is the organ that most profoundly distinguishes human beings from other species, including other primates, and is an extremely complex network of neuronal structures supporting specific personal aspects and characteristics. These include an individual's identity, self-awareness and his or her capacity to reason and make meaningful relationships. This is why so much importance is attached to the human brain and to understanding the very grave concerns that are associated with any direct intervention on any of its parts.[4]

Structure of the Brain

At its peak, a human brain has around one trillion (10^{12}) neurons, each of which is capable of up to 10,000 interconnections with other neurons. This gives the human brain 10 quadrillion (10^{16}) possible connections, enabling, for example, a person to recognise any changes in his or her environment and communicate these variations to other neurons, thereby directing a bodily response. However, as a person becomes older, some of these neurons begin to die so that by adulthood, only about one quadrillion connections remain.[5]

As already mentioned, different functions of the brain are generally associated with distinct areas of this brain. This structure–function relationship occurs not only at the macro-scale, in which the areas are composed of hundreds of millions of neurons, but also at a neuronal micro-scale. As such, the functioning of the brain in terms of processing signals, storing memories and triggering actions is intrinsically associated with the one-to-one linkages formed between the neurons, the types of chemicals used to carry messages between the cells and the relative timings of the exchange of these chemicals. Given that there are billions of neurons, each of which makes tens of thousands of synaptic connections, the complexity of this network is massive.

It is possible to consider the brain as if it were a computer, with a binary 0 and 1 code driving the processing, but this is an inadequate comparison. Computers are, undoubtedly, highly capable and their power continues to expand exponentially. However, the brain's multi-layered complexity makes it a difficult organ to understand at an individual neuronal level. This means that it will take a long time for computers to begin to function at the same level. The pattern and strengths of connections continually change as a person meets new challenges and goes on to record and process each day's experiences. The change can also be dramatic. For example, brain injury where entire areas of the brain no longer function can restrict certain abilities, although after some time, these may begin to return as other areas of the brain seek to compensate. As such, the structure–function relationship can be seen as both necessary and plastic.

Function of the Brain

In 1824 the French physiologist Jean-Pierre Flourens (1794–1867) published the results of a series of experiments in which he removed certain portions of pigeons' brains to see what happened.[6] He found that removing a specific part destroyed the sense of will, judgement and perception of the birds, and that removing another part took away the animal's muscular coordination and its sense of balance. Finally, taking out a third part of the brain, which seemed to contain the cardiac, respiratory and vomiting centres, killed the birds.

On the other hand, Flourens was unable (probably because his experimental subjects had relatively primitive brains) to find specific regions for memory and cognition, which led him to believe that they were present in a diffuse form around the brain. This meant that different functions could generally be ascribed to particular regions of the brain, but that a finer localisation was not possible.

Neuroscientists can now examine the brain in many different ways. For instance, they can study the neurons themselves as the basic building blocks of brain function by examining the detailed biology of these neurons and how the transmission of information takes place. But researchers can also study the brain at a more general level by investigating the way in which neurons form circuits and networks of communication through electrical and chemical signalling, or even examine a certain activity as it takes place in a whole region of the brain.

This last approach can vary from a detailed analysis of a simple memory circuit to broader influences on the function of a human brain using more advanced measuring devices in a conscious human being. Alternatively, instead of examining the brain itself as a biological entity, it is possible to concentrate on the cognitive, social and behavioural consequences of brain function.

At present, most neuroscientists believe that it is necessary to combine these molecular, cellular and circuitry systems all together with cognitive approaches, while seeking to understand human behaviour and social interaction in order to obtain a more general understanding of brain function.[7]

The different parts of the brain include the following.

The Brainstem

The brainstem consists of an extension of the spinal cord with which its organisation and functional properties share similarities. It supports an entry and exit system to the brain for a number of communication pathways that influence elements such as breathing, balance, taste, hearing, the heart and blood vessels.

The Cerebellum

The cerebellum holds more neurons than any other part of the brain, including the larger cerebrum (see the next section), but consists of fewer different types of neurons. The cerebellum modulates the outputs of other areas of the brain to make them more specific. It represents about 10 per cent of the brain's total volume but contains 50 per cent of its neurons. If the cerebellum is removed in an animal, it can still perform most activities, but becomes much more hesitant and clumsy.

The function of the cerebellum includes posture and the coordination of movements of the eyes, limbs and the head. It is also involved in motion that has been learned and perfected through practice and will adapt to new learnt movements. Moreover, it displays connections to areas of the cerebrum that are important for language as well as cognitive functions.

The Cerebrum

The cerebrum (Latin for *brain*) is the largest single part of the brain in humans and is responsible for processing information, using more than 90 per cent of the oxygen supplied to the brain. It contains the cerebral cortex, which consists of two symmetrical parts (cerebral hemispheres) in the left and right part of the skull, between which there is a clear division.

The cerebral cortex is one of the most important parts of the human brain, with different specialised regions addressing motor, visual, auditory and olfactory functions, as well as those for high-level perceptual analysis of faces, places, other persons, learning, speech, cognition and emotional control.[8]

Cerebral cortex circuitry is extremely complex and neuroscientists are only just beginning to use new tools, such as neuroinformatics or network science together with more traditional biological examinations, to try and understand the functional connections within and between cortical regions.[9]

However, one important discovery in relation to the way in which human brains work is that there is no straightforward 'one-to-one' link between brain structures and mental processes, though particular brain areas associated with particular functions do exist. Many cerebral cortex regions have numerous integrating and analytical characteristics. This means that certain brain regions cannot be ascribed to a unique function. Instead, a particular brain structure may be associated with a number of mental processes, while particular mental processes may involve several brain areas.[10] For instance, a number of human experiences, such as the perception of pain, involve a spatial and temporal pattern of activity in multiple brain regions.[11]

Biological Development of the Brain

The brain continues to develop in a human person until about the age of twenty, during which time the wiring of the brain undergoes major changes that are dependent on environmental influences. When a person is born, the great majority of his or her neurons already exist and are in their final position in the brain, though many are still disconnected from one another. New connections are formed only after birth and continue until adulthood. These are then preserved or reduced depending on neuronal activity and any external factors that affect this activity. This means that every interaction with, for example, physical and societal environments as well as lifelong learning processes will influence the arrangement and structure of neuronal connections in the brain. It is believed that this happens as a result of existing connections being strengthened or weakened in relation to how much they are used. This implies that the neurological structure of a mature brain may be influenced by:

– genetic predisposition that determines the general structure of the brain;
– the cellular and physiological shaping of connections that modify the brain in relation to its environment during development;
– lifelong adjustments in response to different experiences.[12]

Many neurobiologists believe that all functions of the brain can be reduced to its structure and the connections between neurons, though it should be emphasised that every function is the result of widely distributed neuronal networks. Thus, for these scientists, the most complex functions of the brain can only be the result of what goes on in the brain. This includes basic functions such as the ability to perceive, remember and act, but also higher functions such as the ability to decide, control attention and generate emotions. Even the ability to understand and generate speech, to consciously deliberate and be self-aware as an independent, autonomous and intentional agent is believed to only be the result of brain structure, the connections between neurons and the signals that pass between these neurons.[13]

The Mind

In the seventeenth century, the French philosopher René Descartes (1596–1650) concluded that 'Cogito ergo sum' – 'I think, therefore I am', or possibly better translated as 'I am thinking, therefore I exist'. At the beginning of an age of observation-based discourse, thinking took on a whole new role, but it also posed a dilemma concerning the possibility of trusting what comes in through the senses. How does one know whether anything one sees, hears, tastes or encounters is real and not just an illusion?

Descartes' conclusion was that the only thing he could trust – the only reason why he knew he existed – was that he was aware of his own thoughts. In his 1638 *Discourse on the Method*, a study on proving self-existence, he indicated that a person would not be able to recognise whether an evil demon had trapped his or her mind in a black box and was controlling all its inputs and outputs.

In 1981, the American philosopher and computer scientist Hilary Putnam (1926–2016) presented a modern parallel to Descartes' argument in his 'brain in a glass vat' thought experiment, in which a human brain was removed from a person's body and suspended in a vat of life-sustaining liquid.[14] He suggested that if the same information from a computer imitating reality was given to a brain in the vat as was given to a brain in a normal human head, this brain in the vat would not know where it was situated. Moreover, it would not be able to distinguish deception from reality. The computer would be simulating reality in such a way that the 'disembodied' brain would continue to have normal conscious experiences, even though these never really happened in the real world.

The brain in the vat thought experiment is often used in philosophy to understand aspects of knowledge, reality, truth, mind and meaning. For example, since it is impossible to know whether a brain is in a vat or a human skull, it is impossible to determine whether most people's experiences are true or false. This then raises questions about how a person can know and be certain of anything.

In Descartes' time, the brain was poorly understood and life was believed to dwell in the blood. The English anatomist William Harvey (1578–1657) had demonstrated that blood circulated around the body, breaking with the historical belief that it ebbed and flowed from the heart. It was also difficult to disregard the critical observation that if the blood was left to pour out of a person, he or she would eventually die.

But the following 300 years saw a gradual shift from blood to brain, with mental reflection being seen as a key aspect of human life and existence. Death can now be defined, in many countries, in terms of an absence of critical brain function (brain death). The heart may still be functioning with a healthy blood flow, but if a person is considered to be brain dead, then physicians can decide that this individual has died.

It is therefore the possession of a functioning brain supporting a mind that seems to matter in modern society in terms of characterising whether a person is alive. However, a long history of philosophy, religion, psychology and cognitive science has been necessary to try to develop an understanding of what defines a mind and its essential properties. And although this is still an ongoing process, a useful definition of the mind in a human being can be characterised as the set of cognitive faculties that enables consciousness, awareness, perception, thinking, judgement and memory to exist.[15]

A mind also allows a person to attribute mental states to other persons, which enables each individual mind to recognise that others also have minds. This capacity begins to gradually develop in children between the ages of three and four, when they begin to understand that they and other persons also have minds.

A further question that can be considered is whether it is only human beings who possess a mind or whether it may be possible for a machine, such as a computer, to also have a certain kind of thinking mind enabling self-awareness. However, this raises the difficulty that it would only be the computer that would know that it existed since, using Descartes' formula, it is not possible to know for certain whether anyone else exists.[16]

The Brain–Mind Interface

By returning to Descartes, it is possible to suggest that human persons are composed of mental 'stuff' that is the basis of the mind that is living inside a body made of physical 'stuff'. In other words, Descartes suggested that the mind is found in an immaterial domain that he called *res cogitans* (the realm of thought). The domain of material things, on the other hand, he called *res extensa* (the realm of extension).[17] He then proposed that the interaction between these two domains occurred in a small midline structure of the brain called the pineal gland.

But while it is accepted that Descartes' explanation may be coherent, few present-day philosophers and other scholars are satisfied with his suggestions, especially with respect to the pineal gland.[18]

Nevertheless, the manner in which mental functions are enabled by the brain is still not fully understood. It is a question that has often been recognised as the Mind-Body dilemma for which many proposed solutions exist, which are generally divided into two broad categories, each with numerous variants:[19]

1. *Dualist solutions*: these keep Descartes' distinction between the realm of mind and the realm of matter, but they give different answers about how the two realms relate to each other, including the following:
   a. Substance dualism: where the mind is formed of a type of nonphysical substance that is not governed by the laws of physics. The brain, on the other hand, is considered to be a kind of physical substance. It also indicates that the two substances may interact with each other in causal relationships.
   b. Property dualism: where the laws of physics are universally valid, but cannot be used to explain the mind. In this way, the mind exists as a nonphysical entity representing a mere property of the physical brain (a sort of side-effect), but not a specific substance in itself.
2. *Monist solutions*: these postulate that there is only one realm of being. Mind and matter are both aspects of this realm. There are three main types of monism:
   a. Physicalism: where the mind consists of matter organised in a specific way.
   b. Idealism: where only thoughts exist and matter is an illusion.
   c. Neutral monism: where both mind and matter are aspects of a distinct essence that is not itself identical to either of them.

Even though neurobiological research has made a lot of progress in recent years, there are still no comprehensive models of this structurally complex and functionally dynamic system. Thus, the ancient debate about the actual relationship between mind and brain, and between mental and brain states, remains unresolved. As the U.K.-based ethicists Sarah Chan and John Harris indicate, 'despite modern scientific understanding of the brain, the philosophical relationship between brain, body, mind and identity remains elusive'.[20] However, it is taken for granted that a person's mental capacities, such as perception, thought, memory, feeling and agency, are dependent upon his or her brain.[21]

Another reason why the brain is crucially important is because of its key capacity to control a whole body. Indeed, the embodiment of a person is an essential characteristic of his or her existence, identity and capacity for perception and action. The brain is also central to the way in which a person interacts through language and emotion. Again, as Chan and Harris indicate: 'The inherently problematic nature of this can be explored through two related but conceptually distinct questions: "Am I my mind?", and "Is my mind my brain?" Clearly, "we" are not just our brains or our minds: our sense of identity is closely associated with our physical bodies; our experience of the world, though expressed in one form as brain activity, necessarily includes the phenomenon of embodiment.'[22]

As a result of neurological research, and especially from the information obtained from brain injuries, it is possible to show that this sense of self-awareness is also based upon non-conscious functions in the brain. These both prepare certain aspects of conscious thoughts while processing the human body's daily functioning, such as breathing and digestion. This means that non-conscious processes, in addition to conscious functions, make a contribution to the way in which persons understand themselves and others.[23]

However, this dependence on the physical brain of a person's sense of self and self-identity may give rise to further questions. For example, it is possible to ask whether an individual is still the same person if his or her brain changes quite significantly through, for example, injury, disease, surgery or even the passing of time. It may also be possible, in the near future, to examine how these changes affect the physical brain, but this may still not provide any final answers.[24]

In addition, the manner in which the mind, including the way in which a person experiences self-consciousness, is related to biology has very important implications to the understanding of free will and responsibility, which has direct consequences on cyberneuroethics. If all the decisions of a person can be reduced to neurobiology or a material basis, how can he or she be responsible for his or her choices and actions? Indeed, responsibility means that an individual has a free will to make another decision.

Would it then be possible, for instance, for persons to defend themselves in court by arguing that it was, in fact, their brains that made them commit a crime? From this perspective, a better understanding of neurobiology may completely change the manner in which free will and responsibility are considered.[25] But whether this may eventually happen remains an unresolved question.

It is also important to examine how external influences may affect the brain and thereby the mind of a person, and whether this would then influence the way in which a person makes decisions. As the North American ethicist Walter Glannon explains:

> [T]he mind emerges from and is shaped by interaction among the brain, body, and environment. The mind is not located in the brain but is distributed among these three entities as the organism engages with and constructs meaning from its surroundings. Our capacity for desires, beliefs, intentions, and emotions, and to deliberate, choose, and act, is grounded in the fact that we are embodied and embedded minds. We are embodied minds in the sense that our mental states are generated and sustained by the brain and its interaction with external and internal features of our bodies. We are also embedded minds in the sense that the content and felt quality of our mental states is shaped by how we are situated and act in the natural and social environment.[26]

This environment, for instance, includes the influences that may arise if the mind is fused with cyberspace through a direct neuronal interface appliance. Of course, such interfaces are relatively unsophisticated at present, but they will be considered in the following chapter in order to examine how information may be directly obtained and provided to the brain.

Notes

1. Bear, Connors and Paradiso, *Neuroscience*; Kandel et al., *Principles of Neural Science*.
2. Shipp, 'Structure and Function of the Cerebral Cortex'.
3. Bear, Connors and Paradiso, *Neuroscience*; Kandel et al., *Principles of Neural Science*.
4. Nuffield Council on Bioethics, *Novel Neurotechnologies*, 73.
5. Moor, *Enhancing Me*, 54.
6. Flourens, 'Experimental Researches on the Properties and Functions of the Nervous System in the Vertebrate Animal', 129–39.
7. Nuffield Council on Bioethics, *Novel Neurotechnologies*, 11.
8. Kanwisher, 'Functional Specificity in the Human Brain'.
9. Shipp, 'Structure and Function of the Cerebral Cortex'.
10. Poldrack, 'Can Cognitive Processes Be Inferred from Neuroimaging Data?'
11. Tracey, 'Imaging Pain'.
12. Singer, 'A Determinist View of Brain, Mind and Consciousness', 41–48.
13. Ibid.
14. See Putnam, *Reason, Truth, and History*, 222.
15. The *Oxford American College Dictionary* defines 'mind' as 'the element of a person that enables them to be aware of the world and their experiences, to think, and to feel; the faculty of consciousness and thought'.
16. Moor, *Enhancing Me*, 62.
17. Dy, Jr., *Philosophy of Man*, 97.
18. Lokhorst and Zalta (eds), 'Descartes and the Pineal Gland'.
19. Jaworski, *Philosophy of Mind*, 5–11.
20. Chan and Harris, 'The Biological Becomes Personal', 49–50.
21. Nuffield Council on Bioethics, *Novel Neurotechnologies*, 73.
22. Chan and Harris, 'The Biological Becomes Personal', 49–50.
23. Nuffield Council on Bioethics, *Novel Neurotechnologies*, 73.
24. Chan and Harris, 'The Biological Becomes Personal', 49–50.
25. Greely, 'The Social Effects of Advances in Neuroscience'.
26. Glannon, 'Our Brains are Not Us', 321, mentioned in Jotterand, 'Moral Enhancement, Neuroessentialism, and Moral Content', 48.

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