The Convergence of Computing, Cognitive Neuroscience, Biogenetics and Biology: The Phenomenon of Consciousness

Charles T. Ross

ABSTRACT

Over the last century our knowledge of every branch of science has advanced at an ever increasing pace, yet now, at the beginning of the third millennium, we are on the cusp of, perhaps, the greatest expansion ever – and in almost every sphere of research. The invention and breakneck speed of the development of computers has played a major role in this endeavour by processing research material, and speeding up communications and disseminating information. Computing is transforming business, commerce, industry, finance, and the basic fundamentals of both education and economics. However, increasingly, we are beginning to realize that this is only just a part of the potential contribution computing science can make. This paper outlines a computer software designer's contribution to the consciousness debate.

Key Words: computing, mind, convergence, consciousness, neuroscience

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Introduction

Just as Galileo looked through his telescope, and Hooke through his microscope, computers are enabling us to see things we had not been able to see before. Craig Venter opens his book *Life at the Speed of Light (2013),* with the sentence "The once distant domains of computer codes and those that program life are beginning to merge" (p.1). Daniel Dennett has included a chapter on 'programming' in his latest book on *'Intuition Pumps and Other Tools for Thinking*' (*2013; pp.*109–132). The Edinburgh physiologist, Jamie Davies in *'Life Unfolding'*, (*2014; p.*4), comments on the valuable insights computing can offer his discipline. UCL is exploring the convergence of carbon and silicon based life forms. David Deutsch and Chiara Marletto, at Oxford are drawing attention to the similarities of human reasoning and gene replication to programming. Evolutionary biologist, Andreas Wagner in '*Arrival of the Fittest' (2014)*, describes the "deep unity between the material world of biology and the conceptual world of computation." He goes further, suggesting computers are also "the microscopes of the 21st century". Synthetic Biology is a reality, and prosthetic brains a distinct possibility.

Corresponding author: Charles T. Ross
Address: 8, Woodford Close, Devizes, Wiltshire, SN10 5LQ UK
Phone: +44 (0) 1380 829 565
e-mail ✉ charles.t.ross@btinternet.com
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Computers supplement our Brains

While telescopes and microscopes supplemented our eyes and launched the scientific revolution, the invention of steam power and electricity drove the industrial revolution. This massive increase in the supply of energy supplemented our muscles. Now computers are beginning to supplement our brains, and the impact of the computing revolution will be orders of magnitude greater than all that has come before.

Now that we have half a century's experience of designing and programming computer systems we can begin to appreciate the contribution that our burgeoning knowledge can make. There are now two information processing systems in the universe that we know about. Throughout natural history, the brain has evolved as a means of organising all the organs of a life form to behave as one cooperative, coordinated synchronised whole. The brain does this by processing information from all its sensory and other organs. The new kids on the block are our electronic digital computers, which can do one thing and one thing only; just process information, and they only have three instructions with which to do this. However, the way computers have been designed teaches us a great deal about the way the systems of the brain achieve their almost miraculous tasks.

The Duality of the Brain

The first and most significant contribution of computing is that it helps us understand the duality of the brain's neural systems that has puzzled humans from the birth of recorded history. The Egyptians used the word *'ka'* to describe the *'vital essence'* that observably departed from the body when people died. The Hindus and Buddhists thought this was a spirit or '*atman*'. Descartes' dualism suggested that 'while the body, of which the brain is a part, works like a machine the mind is not material'. Given the problems that Galileo experienced, it is not surprising he choose to describe the mind as *'soul'*. Charles Sherrington opined that "the mind was invisible and intangible, and *per se* cannot even move a finger, let alone play the piano". By the late 1930's Edwin Schrödinger was sure that both the brain and mind must operate to the rules of physics.

Hardware & Software

The integrated circuits in a computer, mostly of semiconductors that we can see and touch are the Hardware, and we have coined the term software for the patterns of ephemeral electronically coded instructions – the programs - that flow over these circuits. Without software all computers are useless, they cannot even make the tea! Without hardware, software programs have nothing to operate upon.

The brain is observably the physical hardware: the neuron networks, the family of glia cells, the glands, the neurotransmitters, the messenger molecules, and more. We can open a skull and see and touch them all. The mind (or spirit, soul, ka or atman if you prefer) is the mass of ephemeral patterns of electrochemical signals and electromagnetic fields flowing in waves across the brain all bathed in floods of hormones. Without the mind (neural software) the brain is dead. Without the brain (neural hardware) the mind has nothing to operate upon. We could say to Sir Charles Sherrington that the mind may, indeed, not be able to play the piano, but nor can the brain play the piano either. Moving the fingers over the keyboard requires the coordinated activity of both! We can now say with some confidence that both the brain and the mind are equally tangible and measurable, and both operate within the conventional rules of Physics.

Programming

The second great contribution of computing is the concept of '*Programming*': from the design of a system to all the coded functions of a complete software application**.** The crucial essence of software is that it enables a fixed piece of equipment, or hardware, to be used for an unlimited number of applications. We are all familiar with being able to use our laptop to write text one minute, check a spreadsheet the next, then compute some formula, or skype a friend. Same hardware, different programs. Similarly, we have one set of neural networks that, for instance, manipulate the muscles of our lungs, vocal chords, mouth, lips and tongues. Across this single neural hardware system, we can speak every word we know, sing, and play many musical instruments.

The instructions at the disposal of the computer programmer are remarkably modest. There are just three: add, subtract, and the ability to jump to another instruction in certain circumstance. Alan Turing outlined this 'software' system in his famous paper 'computable numbers' to the Royal Society in 1936, which he described as a processing 'machine'. In many ways the Mind, as opposed to the brain, can be seen as a Turing 'machine'. We *invented* software programming and coding. In the process we have *discovered* the software of biogenetics, neuroscience and biology et al.

We are increasingly realizing that this software, hardware dichotomy is common to many things. It is basic to the operation of the genes, how we learn from experience; and in other species, how bees operate as hives, fish swim in shoals and birds fly in flocks. There is increasing evidence that computing has enabled us to explore a whole new discipline: the science of software. For centuries we have really only known about the 'hardware'– what we could see and touch. We are now beginning to realise even in computing itself, but also in biogenetics, in biology and in psychology that the software actually plays the dominant role. Current computers are largely transistor based, but researchers are racing to build quantum, biological and light based processors using new materials recently discovered. They all depend on software, and the same basic software architecture will work on whatever hardware is invented.

Creativity and Evolution

Our knowledge of the hereditary transfer of physical information from one generation to the next via DNA is advancing by leaps and bounds. This 'Darwinian' evolution accounts for the growth of our physical structures - all our cells and organs including the brain: the *hardware* of our body. Computer science is helping us understand that there is a parallel process. We buy a new word processor software program and replace the previous version by uploading it to our lap top.

Learning a new language is a bit more difficult. The knowledge of the hereditary transfer of the information that flows over the brain: the *software,* is by learning and education. For instance, language is not inherited through our DNA. It is one of many skills that has to be learned by each individual from their parents and peers. It is part of what can best be described as cultural evolution. Classical - Darwinian, or *hardware evolution* advances very gradually over many hundreds of generations. *Software evolution* can advance significantly within one single generation.

Advances in Biogenetics and our growing understanding of the plasticity of the brain in the context of software systems design is giving us a framework to develop a logical architecture for creativity. We are beginning to identify more than one stream of evolution and a logical explanation for each.

The Five Great Questions in Neuroscience

The five great questions in cognitive neuroscience divide into two pairs: i*nformation and memory*; and *intelligence, thinking* and the family of *creativity*. All four contribute to the central question that has fascinated mankind throughout recorded history: *Consciousness*. Computing and particularly software science makes a major contribution to all five. The five are interrelated but we can study them in this sequence. Then, by comparing and contrasting our electronic brains with our natural ones we can venture some definitions, and outline the potential future of computing.

1 and 2 Information & Memory

Information and memory are the foundations of all our knowledge and understanding of everything. Information is what we store, remember and recall. Without memory we could not recognise that things we are witnessing might have occurred before and react accordingly. Without memory we could not learn from experience and build up our knowledge. *When we are born we can do almost nothing, but we can learn to do almost anything.*

Introduction to Information

There are four types of information. (1) There is the *physical information* of the natural world all around us; how everything works and how everything happens. (2) There is biological information - the way information is passed from generation to generation – *biogenetic information*. And how plants and animals are nourished – photosynthesis, for instance. Then there are the ways that animals in general, and human beings in particular, use and process information – *neural information*. The sensory and other organs generate a continuous flow of information as they monitor what is happening in the external environment. Similarly, the autonomic, hormonal and immune systems generate a flow of information in the body. (3) *Human information*. We have developed various forms of specialised information systems, most typically *speech and language*, but also mathematics, and notations, symbols and descriptors of music, formulae and much else. (4) Lastly we have invented a complete matrix of artificial, or *machine information* which drives all our communications and computing systems.

Machine information maps very efficiently onto language and mathematics, but we can observe that language does not completely map onto neural information, particularly the internal functions. There are quite large areas of our experience that, although we have had speech for at least ten thousand years we have not developed words and phrases to describe many of our experiences, particularly our emotions, perceptions, impressions and sensations. We cannot accurately define many of our feelings of attraction, beauty, leadership, and so forth. We use the word qualia for this family of experiences. Many people have found this a problem in our understanding of ourselves, but actually it is a valuable pointer to the construction of theories of our knowledge and understanding of consciousness. We should ask ourselves "what is the reason barrier to finding words and phrases to accurately define some of our most basic emotions?"

In another dimension there is information that is valuable of itself, and information that is of little or no direct value, but enables us to find information, like formulae, recipes and algorithms.

To help define information Claude Shannon argued that Information is the *unifying principle of science*, while John Archibald Wheeler suggested that in due course we will have learned to understand and express all of physics in the language of information. Put another way, the laws of physics are the algorithms of the processing of information. Perhaps we can go one stage further? Biogenetics, neuroscience and computing are all about different aspects of processing information. Different Facets of similar functions.

Introduction to Memory

Memory is a complete subject in its own right. At this point in the argument it is important just to note that computer hardware is fixed. Everyone can only work with what comes from the manufacturer. The brain – particularly defined as the hardware is very different. We are born with some two billion neural networks, half connecting up every organ in the body and half concentrated in the brain. A mature brain has grown upwards of a trillion additional links and structures, holding the massive memory systems of all our experiences - of the order of one hundred thousand words for starters - and that is just one language. We grow the neural circuits to learn to walk, talk, run, write, swim, code, number and drive cars virtually automatically. Donald Hebb summed up the process: - "*neurons that fire together, wire together*". We can discuss elsewhere how this forms, then strengthens memory, and also study pointers to how the memory systems degrade: dementia and other malfunctions. It is noteworthy that the term *'plasticity'* is back in fashion to describe how the brain is continuously growing, reorganising and replacing worn or damaged functions.

The brain mind has primarily evolved as a '*learning system*'. Information and memory are tied intimately together. Indeed, static information, or memory, can be said to be '*potential information'*. Streams of signals transmitted through the system can be said to be *'kinetic information'*. They do work. The latter grows the former. The former regenerates the latter. The software of the mind grows the hardware of the brain!

However, information, whether active or stored in memories, is only of use if we can put it to use. There is the whole subject of the conversion and translation of pure facts into *meaning*: the *implications* of pure information. The *extrapolation* of simple lists of data to solve problems. As the brain processes information the whole body reacts, and can be instantly ready to respond. No computer has any concept whatever of what it is processing.

3 and 4 Intelligence, Thinking & Creativity

The third and fourth questions centre around the great debate over what we mean by intelligence. We can observe natural, autonomic intelligence; the great coordinator. Intelligence is the essential skill all brains have evolved to enable the fastest possible response to incomplete information: that way we survived. The ability to identify patterns in masses of information. To respond to the unexpected.

But then there is the apparently unique human skill of prediction, imagination, invention; abstract ideas and concepts. The whole family of creativity; not only the arts, crafts, sciences and entrepreneurship, but in every aspect of life. Creativity, so crucial to us, and apparently, completely absent from our computers.

5. Last, and Fifth, But by No Means Least is consciousness

All four add to our understanding of consciousness; however, the contribution of computing is moresubtle. The triumvirate of biogenetics, cognitive neuroscience, psychology, plus software science can make a surprisingly massive contribution by highlighting what we would have to design and build into our computers to emulate what nature has endowed us with.

Greatest Contribution of Computing: Clues to Consciousness

Perhaps the greatest contribution computing can make is to our understanding of the most difficult problem of all: consciousness.

We can now say with some confidence that *"the brain is not conscious"***.** This is a startling statement, but we can see that it is true from a number of perspectives. All our efforts to generate artificial, or machine intelligence in our computers have been designed into the software. Bigger and better hardware has played its part but only as the medium on which all these programs operate. Artificial, or machine information is all about the software coding systems. If we want to try and emulate thinking, let alone consciousness on our computers it will have to be done in the software, unless, or until we can design computer hardware that can self-reproduce itself.

Descartes opined that the pineal gland might be the seat of consciousness. No less a luminary than Francis Crick was attracted to the idea that the signature of consciousness might be generated by the oscillations of pyramidal neurons, not least because these cells appear to be exclusive to humans.

We have known for some time that the brain does not feel pain. If we stub our toe we see this happen numbers of milliseconds before a message reaches the brain. The brain modulates the message but the sensations of pain are experienced by the whole body. Brain surgeons regularly operate on the brain structures without need of anesthetics.

It is increasingly clear that *consciousness is generated by the mind* - the software - the continuous living mass of patterns of electrochemical signals stimulating the glands to output floods of hormones that cause the whole body to experience sensations, perceptions, impressions and emotions.

To support this argument, we can observe that conscious experiences are a series of *processes.* In the eighteenth century David Hume argued that "if the brain stopped thinking, the conscious self-vanishes", and this has largely been the accepted wisdom ever since. Arguably, he was close to being right, except that the mind never stops processing – it is a definition of us being alive. Whether the electrochemical activity generates a conscious experience depends on the *state* of the neuron networks – the brain. Both the processes of the mind and the state of the brain need to be operational. We can look at this the opposite way.

The brain - the mass of neural networks, glia cells, neurotransmitters, messenger molecules – the hardware – remains intact after death, but self-evidently that person has completely lost all sense of consciousness. Observably something else generates 'consciousness'. Similarly, the billions of nucleotide base pairs in the genome do not create the amino acids and the proteins that create a baby child. The molecules in an acorn do not grow an oak tree. In every case something else is needed.

The neurons of the brain need the electrochemical activity of the mind. The circuits of semiconductors need programs: the base pairs need energy to select sequences of codons to create RNA, which in turn organises the building of amino acids and so forth. The molecules in an acorn need energy – warmth – and water to start building shoots, leaves, and set in motion photosynthesis to grow whole oak trees. In each case the transistors remain unchanged: the neurons are not destroyed – they grow extra links: the genome remains intact. They all act like catalysts. The work is done exclusively by the software, which always makes the maximum possible use of the structure and framework.

A good analogy suggests that the transistors in computers, the neurons in the brain, the base pairs in the genome, and the molecules in a seed are like bricks and beams. Carefully assemble these components in the right patterns and structures and together they can create a house. Put some energy and paraphernalia of everyday life into that house and it begins to reflect the characteristics of a home. When our eyes meet a stunningly attractive person across a crowded room, signals flash across the neurons stimulating the glands to output testosterone, adrenalin. We begin to feel very alive, our inhibitions fade and our muscles brace up to make a good impression, and our whole body is conscious of a growing sense of excitement.

Evolution of consciousness

Most animals, certainly all mammals experience the sensations of hunger, thirst, fear, aggression, attraction. The sensory organs monitor the environment, internal and external, and transmit patterns of signals across the neural networks. This activity stimulates the glands to generate a mix of hormones which creates an emotional sense of awareness of our surroundings. To *be aware* that one was running for one's life, gave the opportunity to react unexpectedly and survive. So any advance of this skill was selected for. We react by a combination of muscular activity moderated by the hormone mix. We run away, prepare to fight, search for food and water; reproduce. This behavior is pretty much standard across the animal world, but also in babies. When a child is conscious of being hungry it learns to yell until a parent comes to feed it. We are conscious from very early in life. Gradually, gradually our conscious experience expands.

Monitoring and Feedback

The huge advance from such primitive reactions to the multifaceted consciousness we experience is primarily due to our development of language. We have discussed elsewhere the ability to interrupt the conditioned response and provide time to pause the system and evaluate alternatives, and then, and only then decide on the best course of action (the Zeno effect). In parallel we developed the ability to monitor our own behavior and the reactions of others. We inherited these basic facilities from deep in our ancestry. Every dendrite from the brain to every muscle is matched by a parallel reciprocal axon feeding information back to the brain, confirming that the action originally ordered has been executed efficiently. Many mammals have 'mirror' neurons that mimic the behavior of others and are active when we see others behave as we might wish to do so. Gradually the executive brain systems have been augmented by a parallel feedback and monitoring system, which enabled our ancestors to begin to moderate their behavior in the light of the responses their behavior generated. Feedback and monitoring systems enable any system to become more efficient, but the development of language allowed these reactions and perceptions to be discussed, debated and the experience of others added to the mix of each individual. A feedback system suggests a possible delay between the original act and the processing of the feedback from its effect. This accounts for the phenomenon, very much debated recently, that there often appears to be a delay between some executive action of the brain and our apparent consciousness of it. There is no 'free will' issue here of who is in control. It is 'I' deciding and 'me' checking up.

This parallel second system monitoring our autonomic responses proved to be very valuable and survival selected for its development. The 'Zeno' ability to interrupt and evaluate alternatives solutions, the capacity to monitor behavior and feedback the effects, and, above all, the ability to discuss and debate individual and group experiences was a very powerful mix. It is working ever more energetically for us to this day. It is one of the major components of all research!

Language

Language provided another boost to these developing facilities. The key value of language is that it necessitates ascribing meaning to words, and then phrases. Meaning is an integral part of consciousness. Many observers argue that the words in a language started life as labels to things and actions. Thus the visual sensation of a tree was linked to the verbal sensation of the sound 'tree'. We take for granted that we see, hear, feel, smell and taste and have sounds, images, feelings, smells and tastes stacked up somehow in our brains, along with a series of dictionaries full of words, and encyclopedias full of images, recently supplemented by Wikipedia entries.

However, we are also beginning to appreciate that neither we, nor our computers, have anything of the sort. Neither have we one single word, or image, or scent, or feeling or taste. Computers have complex coding structures we have invented to represent, what we call 'information'. The mind represents all this 'information' as a matrix of perceptions, impressions, sensations and emotions. We are so familiar with this whole process that we have the sensation that we see an image. Surely it is the patterns of energy – photons - that strike the retina? Well 'no'. The retina translates these patterns of photons into patterns of electrochemical signals, which are transmitted to the brain – almost the whole brain is involved in one aspect or another: edges and shapes in one place, color in another. What we experience – are conscious of - is a representation of those images. Mostly what we experience at any one moment is the neural patterns representing images we have remembered from the past, updated by any modifications; or mosaics of past memory components. If this sounds unlikely, close your eyes, and you will still be conscious of all the components of the images you were looking at. You can even zoom in to detail: follow a path as though you were walking along it.; answer detailed questions about that image, and where and when you have seen it before, and what was happening when that occurred. We experience the sensation of seeing, hearing, tasting, touching and smelling. Language allows us to classify and define them, pigeon hole them so that we can discuss them, describe them in a form others can participate. Thus we are consciously aware of the world around us.

Time, past, present and future

However, language has done so much more. Communication widened our horizons and in particular opened up the fourth dimension. We became conscious of the passage of time. We could reminisce about past events, and use those experiences to improve our responses to present situations; but, of even great significance, we could begin to extrapolate these experiences to predict the possible course of future events. We know of no other organism that has this facility. It is, arguably, the most important attribute we have acquired. If we can envisage what may happen in the future, we can prepare for possible eventualities. We can begin to influence our environment and take increasing control over our surroundings. We are no longer entirely at the mercy of events.

Abstract Processing

We have observed that we can interrupt the automatic response to evaluate alternatives; we can discuss, debate, interrogate and speculate about the implication of the knowledge we have experienced; and extrapolate our experiences to speculate about the future. We can discuss all this with others, or review and assess all this silently to ourselves.

We can build vast complex abstract structures; imagine the plots of novels; iterate possible solutions to problems, compose music in our minds. Establish memories of all this as though they were reality. This *whole process can be entirely abstract*, purely a mass of electrochemical signal patterns. As a result, *'I'* can go one step further and speculate, wonder and guess how every detail of all this will affect *'me'*. It is a small step to angle our thinking and planning to benefit ourselves and our prospects. We can begin to build ambitions and the possible activities that might enable us to achieve these objectives. We are building the characteristics of our personalities. What we think we are, how we might behave and what we might be able to achieve. We are increasingly conscious of a sense of self. A sense of being alive. A sense of agency – of being in control of ourselves and our lives, to some extent at least.

This mass of additional facilities has expanded the capacity of our brains. Not just the ability to store, process and access at least one hundred thousand words – in just one language – but also their meaning, and the meanings of groups of words – phrases – and then, in addition, a vast cornucopia of abstract ideas, concepts, imaginings in a myriad of subjects and themes. A staggering mass of electrochemical activity – software - continuously growing supplementing and extending the neuron networks – the hardware. It seems more than likely that the pyramidal cells discovered by Francis Crick – possibly the largest and most complex neurons we have discovered to date, may well have evolved to help moderate and support all these facilities.

Initiation of neural activity

This leaves us with one last attribute. The ability to initiate neural activity. To instigate a completely new idea – to think of a completely novel line of reasoning – to create a solution to a problem never previously conceived. The basis of Leonardo da Vinci's famous remark that. "*Every single idea, every single concept, and every single piece of information we have about our world and how it operates has been conceived originally in a human brain".*

It is not too difficult to see how we might build one idea upon another, to match two thoughts together and realise they are more than the sum of their parts. But to think of something absolutely new for the very first time: very difficult. Careful observation suggests that the basis of the evolution of all life forms is incremental. The study of all the biological systems of the brain superficially follows the same logic. With one great difference. Abstract thought is mental activity neither stimulated by, nor dependent on, nor tied to, the sensory organs.

All computers are driven by their programs, originated externally, and loaded into their processors. Brains have neither programs nor processors. All living beings are driven by the surrounding events. The Brain is driven by the signals from all the sensory organs. No computers invented today, or even in prospect by the most inventive science fiction authors can think in the abstract: it is a contradiction in terms. However, humans do. Look at the evidence. We can interrupt the automatic response, pause and evaluate alternatives: stop and think. In 'Bright Air, Brilliant Fire' Gerald Edelman calls this the 'remembered present'. We can create imaginary situations and commit whole parallel worlds to memory and we can retrieve that memory and carry on with our imagined existence. The emphasis here is consciously being able to stimulate that memory retrieval: self-stimulation; sometimes called 'self-starting'.

Concentration

Concentration is a very valuable attribute. It is a hard skill to learn for young children. A hard skill to learn for adults. Yet most people can concentrate effortlessly on their hobbies. Watching a play, or film, we can become completely absorbed and oblivious of everything else. Learning to concentrate is about taking control, consciously, or unconsciously of parts of our brains: giving priority to some activities and downgrading the significance of others. We can observe we can do two tasks in parallel. A good example is driving a car and carrying on a conversation. If the conversation takes preference, we suddenly find we are at our destination! If we see danger, we drop the conversation. We use the term *'autopilot'*.

Control

More recently we have learned more about the nutrient path. In particular the astrocyte cells that pass nutrients from the blood supply to individual neurons. Is it possible we have direct neural control over their operation? If we want to give priority to one brain operation can we accelerate the flow of fuel to selected neurons?

Similarly, we are learning more about the control oligodendrocytes exercise over the myelination of neurons, which appears to affect their memory storage capabilities. Could we have, or learn to exercise neural control over the selective activities of these cells?

All down though history we have tended to equate consciousness with being awake and unconsciousness with being asleep. And the subconscious as 'sort of' being always present in the background. Perhaps we should uncouple these processes of consciousness and states of being awake, because observation suggests they do not quite fit.

It is possible to be asleep and conscious, or at least largely so. We call it *dreaming*. Sleep walking is less common, but this suggests we are awake but not conscious. Let us explore uncoupling consciousness from being asleep or awake. We can observe a gradient, from anesthesia to deep sleep, rapid eye movement REM sleep to drowsiness, to daydreaming to being alert: from being unconscious to being aware, up to full concentration. Being asleep and being conscious do not map exactly together.

Process and State

We have set out above the *processes* by which the neurons and hormones generate the perceptions, sensations, impressions and emotions of consciousness. Whether we *experience* that consciousness depends on the *state* of the gradient of being awake or asleep – whether those sensations travel through the system - and that could depend on the very sophisticated way that neurons are connected together – the Synapses.

Synapses

Synapses are very interesting because they seem overly complex, for what they apparently do. Unnecessary complexity is not common in the natural world.

All the neurons are connected to the sensory and other organs, the muscles and other neurons by a narrow gap, or synapse (from the Greek for 'clasp'). Electrochemical signals flowing along the axons to the synapse stimulate the production of neurotransmitters, which flow across this synaptic gap, or cleft, stimulating a similar reaction on the other side of this connection. The strength of the signal transmitted across this gap is modulated by the strength of the incoming signal, the volume of neurotransmitters, and the ambient hormone chemical mix around this junction.

Variable width Synaptic gaps

But why a gap? How wide is this gap? Are the gaps consistent across the brain? However, a much more interesting question is whether these gaps are fixed or variable? It is entirely plausible that the width of the synaptic gaps is determined by the tension across the synapses, and this tension could well be variable in different areas of the brain at different times and for different reasons in different circumstances. The most likely determinant of the level of synaptic tension is the strength of the power supply. If the power supply begins to drop – after some hard work, or a tough day, then the tension will begin to drop and the synaptic gaps widen. Neural messages will continue to be transmitted but less efficiently. This is congruent with falling asleep.

As the energy levels rise after a period of inactivity or rest, the tension will begin to rise and the synaptic gaps narrow. Neural messages will begin to be transmitted more efficiently. We wake up. And all the sensations of consciousness flow again. This scenario closely fits our observed experience. Sections of the brain may well be in tension while other parts are not, hence we are only partly conscious when *dreaming*: the opposite in *sleep walking*. A sharp *knock* to the head quite literally knocks the synapses apart, and we are instantly unconscious. In a *crisis* selected areas are flooded with hormones to maximise our chance of *survival.* The synaptic tension is highest in these areas and so has the highest concentration of energy to maximise the efficiency of our processing – *concentration*. The synapses of areas of the brain operating on *autopilot* have lower tension than others, but only marginally so, thus priority for attention can be *switched* instantaneously.

Two Functions

We are left with a very attractive solution. Consciousness is one function and sleeping is another. They are not the same, nor are they different versions of the same facilities, and it is likely that they evolved for different reasons. The *state* of being either asleep or awake varies according to the energy available to maintain synaptic tension. In periods of intense activity, we deploy every scrap of energy to survive. When we concentrate we throw all available resources at that part of the brain that has the best chance of ensuring our survival. After an emergency, or just a hard day, restoring energy levels has always taken precedence over maintaining synaptic tension. The synapses drift part. Electrochemical signals continue to pass but on a reduced scale. The whole process is a principal function of the age old Autonomic system to maintain equilibrium, preserve energy and survive. Speed of reaction took precedence: both important attributes of intelligence.

Consciousness, on the other hand, appears to be a much more recent phenomenon and evolved to continuously *process* feedback and to pause and learn to *improve* the automatic responses; build better neural algorithms; *to think*. There is a strong argument that consciousness is a function of language. The ability to identify, describe and discuss these sensations and experiences vastly multiplied their power. They provided humans with a 'killer ap' no other species can match.

The patterns of electrochemical signals – the mind stimulates the glands to generate the sensations of the *processes* we experience as consciousness. Tension across the synapses, and therefore the physical width of the synaptic gaps in the brain determines the volume of electrochemical signals that are transmitted and therefore the *state* of where we are at any one moment on the gradient from being anesthetized to being asleep to being awake or concentrating hard. The software does the first job; the hardware does the second.

The transmission of patterns of electrochemical signals *are continuous* even when we are fast asleep – on minimum power. We know this because if we are asleep and someone calls our name or shouts a warning, the synaptic tension is ramped up and we instantly wake up. This continuous background processing is a principal function of the *autonomic system*, which is best described as the *'operating system'* of the whole body.

Sleep can progressively switch off areas of the brain leaving enough areas active to experience limited consciousness – dreaming. Usually the motor neuron circuits close down first so we have the sensation of being unable to move. As we drive a car and hold a discussion concurrently, we are fully awake for one activity, yet easily be completely unconscious of the traffic around us: selective states over which the processes do or do not flow.

The Mind generates Consciousness

The Brain determines when we are Awake or Asleep

This would appear to provide four types of experiences, but all the brain and mind functions are analogue, so all the states and processes are gradual. They both vary along gradients. At one extreme the glandular system is at full stretch and we experience intense sensations and the highest levels of concentration and consciousness deploying all our reserves of energy. Conversely we are in deep anesthesia. If minimum neural activity generates any glandular activity it is too weak to penetrate the system. Synaptic tension is also minimal and reviving us may even be difficult. In between there is a plethora of states, dreaming, day dreaming, concentrating so hard on some problem that we are oblivious to our surroundings. We have the facility to discuss the genius of the human brain mind with other people or contemplate the phenomena silently within our own heads. The better we understand our selves, the better able we are to make the maximum use of our skills and talents, and steadily increase our control over ourselves.

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