Research Essay

The Reasonable Ineffectiveness of Mathematics in Neuroscience

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Abstract

One of the leading theories about consciousness is Integrated Information Theory (IIT) which presents a mathematical equation that will calculate a Φ value based on probability distributions of the brain as a whole and its various regions that perform different functions. This Φ value then generates a multi-dimensional shape in a hypothetical space called qualia space which actually defines our conscious experience. As its name suggests IIT relies heavily on the reasoning that led to information theory and digital computing and telecommunications. It is argued that as numbers do not exist in Nature it is impossible for an organic brain to perform as a digital computer. However electromagnetic radiation (EMR) does exist in Nature and EMR is capable of communicating information. A theory is presented that information in the brain is communicated via brainwaves at the speed of light and that the brain is in fact an electronic device that acts as an analog computer.

Keywords: Consciousness, mathematics, Eugene Wigner, information theory, electronics, IIT, brainwaves.

One of the leading theories about consciousness is Integrated Information Theory (IIT) which seeks to explain how consciousness is generated in terms of a Φ value that is computed as the difference between a probability distribution for the 'state' of the whole brain and the product of the probability distributions of the 'state' of the various regions of the brain that have conveyed information contributing to that conscious 'experience'. This Φ value then generates a multi-dimensional 'shape' in qualia space (Q) that generates consciousness in us. IIT relies very heavily on information theory that is the foundation of digital computing and telecommunications. In short IIT seeks to explain consciousness in us as if we were a Turing machine.

Analog vs. Digital

The idea of calculating by making a machine that models calculations by analogy is very old indeed. One of the earliest timepieces, or clocks, is the hourglass. The hourglass may have been in use over 2,000 years ago, and is a good example of an analogue computer. The sand falling through a small hole in the glass vessel, controlling in a regulated way the amount of sand passing through, models by analogy the passing of time. This means that the hourglass can 'measure' time as a function of sand accumulating in the bottom of the glass. History is full of

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analogue computers, some, but not all, associated with computing time. We find not only hourglasses, but sundials and water clocks, all of which modelled time by the change in volume of some material or position of some regular relationship (for example, of the earth to the sun). Even mechanical clocks are analogue devices, as they model time as a function of distance around gears, pulleys or cogs.[1]

Analog computers do computation by analogy. The first mechanical calculator combined a series of gears, cogs, rods and pulleys in a synchronized structure. These connected mechanisms could be turned, by hand, so as to model systematically the actions of calculating, adding and subtracting numbers, by analogy with the movement of these gears, rods and pulleys. What this means is that by placing ten equidistant teeth on a gear, the proportion of each tooth of the gear is analogous to one of the ten decimal numbers (0–9). What these devices did was to model numbers as an analogy of distance. By aligning a number of gears, each with ten equidistant teeth, you could make your device combine numbers and calculate them by simply moving the synchronized gears through a specified distance.[1]

Another form of computation by analogy that was being used from the middle of the nineteenth century was to actually model, in miniature, the electrical network that you needed to measure. These electrical analyzers were literally a scale model of the network that was being examined. On a large table – and they were often called ‘artificial electric lines’ or ‘short-circuit calculating tables’ – engineers would assemble a number of electrical components which would act in a sufficiently analogous way to the electrical lines, boosters, loads and connections that they were proposing to build. This analogue electrical network could then be powered, and changes in loads along different lines and at specific points and connections could be tried out and the impact on all the network measured directly.[1]

These network analyzers were basically scaled-down models of the electrical properties of an electrical power grid. However, rather than actually build a model of the electrical network – though this was sometimes done – generators, lines and loads were replaced with small electrical components whose input and output were proportional to the system being modelled. Some of these network analyzers were fixed analogues of actual systems, while others were more flexible mechanisms which could be configured using power cords plugged into plugboards like an old-style telephone exchange. Since the electrical analyzers were mostly a series of power sources connected to a network of capacitances, resistances and inductances – basically the electronic bits you need to increase or decrease electrical current – these analyzers could be, and were, used to model just about any ‘network’ problem: electrical loads and resistances, even ‘outages’, also seen as analogous to flows of natural resources, the movement of goods in the economy, population movements, or interactions of capital. As today, such socio-economic problems were modelled using algorithms and mathematical models. The electrical analyzer was a computer that allowed such models to be built and run, using different parameters, or criteria. However, rather than using digital logic to run a program to emulate the model, these computers ran the model by physical, or electrical, analogy.[1]

As networks, and their models, grew in extent and complexity, the network analyzers grew in complexity as well. In 1919, a young scientist, Vannevar Bush, had just joined the teaching staff of the Department of Electrical Engineering at MIT (Massachusetts Institute of Technology), in Cambridge, Massachusetts. Three years earlier he had completed, in one year, his doctorate at MIT on 'Oscillating-current Circuits: An Extension of the Theory of Generalized Angular Velocities, with Applications to the Coupled Circuit and the Artificial Transmission Line'. In his dissertation, finished far too quickly according to his supervisor, he had proposed a new modelling concept for power systems that used a transformer (a device for increasing or reducing electrical current) to represent the loads within the network analyzer. In principle, this allowed for much greater accuracy and complexity in the analysis, and his model was put to the test at the end of the 1920s. In a joint project between MIT and General Electric, a network analyzer (the MIT Network Analyzer) was first demonstrated in June 1929. It consisted of eight phase-shifting transformers, using Bush's design, to represent synchronous machines, 100 variable reactors, 100 variable line resistors, 32 fixed capacitors, and 40 adjustable load units. A very large electrical device, it was spread over four panels arranged in a U, with tables in front for the sensitive thermocouple instruments for measuring the interactions. Though primarily a proof-of-concept analyzer, and for teaching purposes, the MIT Network Analyzer saw considerable improvement and became a 'differential analyzer' capable of solving first order and second order differential equations. Computing in the modern sense of the word was born.[1]

This first computer had both mechanical and electrical components. The room-sized Analyzer incorporated six 'Thompson' integrators, each with an electric motor. There were many metal shafts connecting the integrators and coupling their rotations, which were analogically proportional to the variables for whatever problem was being solved. There was also an 'output table' which plotted the results. The Differential Analyzer had to be 'programmed' for a specific problem by entering the data into three 'input tables' and repositioning all the shafts and gears. This job of 'programming' often took two or more days. However, with an accuracy averaging about 98 per cent, this was one of the fastest and most accurate network analyzers available at the time, and was immediately put to use.[1]

As the mechanical analyzers had to be set up by hand, usually with spanners (wrenches) over many hours and days, they were laborious to program. In addition, any wear to parts, gears or integrators could add unacceptable errors to the system. The technology advanced rapidly with many of the mechanical devices being replaced with electronic components. Vacuum tubes, relays, sensors and amplifiers were all now controlled by a program punched onto a paper tape. This vastly reduced the error and increased the accuracy and speed.[1]

There were also electrical analyzers and other network modellers. We find many devices for drafting, planning and mapping being used. Sextants, used by mariners to determine their latitude at sea, are an analogue computer, as are the much older astrolabes for calculating astronomical movements. More up to date, almost all recording and broadcast media of the nineteenth and twentieth centuries were analogue devices. Film gave the appearance of movement by passing calibrated still images through a projection device; phonographs recreate sounds by analogously engraving sound waves onto a disc; even TV and radio, until they went digital at the turn of the twenty-first century, modulated analogue radio waves modelling sound and vision. Until we all had LED screens, even our digital computers had to modulate our screens using an analogue signal.[1]

One reason that analogue computing was so successful, as a computational system, was its speed. In fact, even today there is still active research into analogue computing because of its speed and accuracy in calculation (mathematical computation). The reason that analogue computing is, and was, so fast is because it does calculations directly.

Numeral	Baudot's 5-bit code*	ascii 8-bit code	Binary number
0	10110	00110000	0000
1	10111	00110001	0001
2	10011	00110010	0010
3	00001	00110011	0011
4	01010	00110100	0100
5	10000	00110101	0101
6	10101	00110110	0110
7	00111	00110111	0111
8	00110	00111000	1000
9	11000	00111001	1001

Comparison of Baudot's 5-bit code, ASCII 8-bit code and the binary number for the numerals 0–9. Numerals in Baudot's code would have to be preceded by a shift code of 11011.

When a digital computer, on the other hand, does something simple like adding two numbers together, it is, in fact, performing a rather complicated procedure. First of all, a digital computer, despite what you have always been told, does not store numbers in binary. Though the digital codes for numbers are binary, having only two states, they are not binary numbers. We can see this more clearly in the preceding table which compares Baudot's 5-bit digital code for numbers with the ASCII 8-bit digital code and binary numbers. Though modern computers store numbers, and characters, as 32-or even 64-bit addresses for codes, these codes do not correspond to the binary numbers as numbers. So the first thing that a computer has to do before it even begins to add two numbers together is to translate the digital code for the numbers we enter into binary numbers. Then you would think that a binary computer would simply add the two binary numbers together as we would:

0011	3
0101	5
1000	8

However, computers do not work with numbers like this. In fact, they do not compute in this sense at all, but, instead, process digitally encoded input, literally just a single electrical current being either on or off, through a series of logic gates.[1]

To add the two numbers above, a digital computer would need no fewer than four 'adders' consisting of four logic gates each. That is a total of sixteen logic gates to add these two numbers. Of course, at the end of the addition, the computer would again have to translate the binary number (1000) for 8 into its digital code (111000 for 8-bit ASCII, for example) so we could then read the result on the screen as an '8' – of course only after the computer had also gone through a large number of processes to actually render an '8' on the screen, in the right font and size, and in the right place.[1]

Today, digital computers have vast quantities of transistors (logic gates) and can do this seemingly complex operation at extraordinarily fast speeds. However fast, though, they still have to do it at the speed of electrical transmission. They cannot go faster. And, in the past, digital computers didn't have anywhere near as many transistors (logic gates) as they do today. In the 1950s, and even in the 1960s, this was a serious limitation on the speed of calculation for digital computers. It was only by the 1970s and '80s that digital computer chips became large enough (and, ironically, small enough) to achieve truly large processing speeds and accuracies.[1]

For analogue computers, this speed problem did not exist. The reason was that analogue computers compute, literally add and subtract numbers, by merely increasing or decreasing the electrical current by the necessary amount or, as was the case early on, through the mechanical distance of cogs, wheels and shafts.[1]

The quantities being calculated in an analogue computer are analogous to actual distances that wheels or shafts move, or the actual quantities of electricity in a circuit. So if we were to solve the above addition problem with an electronic analogue computer, we would simply have a register of current that we could read, and then input 3 units of electricity followed by an increase of 5 units of electricity and instantaneously read the result of 8 units. To subtract we would just take the 8 units and decrease the current by 5 units and be back at our original 3 units, instantaneously.[1]

Engineers in the 1940s, '50s and '60s had devised a staggering array of different electromechanical means by which to do everything from simple arithmetic to complex mathematical calculations, all at astonishingly fast speeds. It wasn't until the late 1950s that the sheer power of digital processing was able to begin to match that of analogue computers for mathematical calculations. Even today, there remain areas of research that are working with and developing analogue computers that cope with certain very complex computational problems that are simply too big for digital computers. Current problems of complex image processing, neural networks and Big Data analysis involve so many data points that we are reaching the limit of what digital computers can cope with – within reasonable time spans.[1]

There are problems today that use techniques, such as fast Fourier transforms, where, with the very large datasets we now have, a digital computer would need many hundreds of years to solve the problem. New analogue computers are being designed that could solve these huge mathematical problems in a few days or weeks, rather than after the hundreds of years that even current digital supercomputers would require. So, if analogue computers are so good at computing, why are we not all using analogue computers? There are a number of reasons, however, one major reason is that, from the earliest times to today, you cannot build an analogue computer that is 'universal'. What this means is that each analogue computer has to be designed to solve a single problem or a single kind of problem. We could say that the nineteenth century and the first half of the twentieth century was the age of analogue devices, but what you notice, if you look at the computational and information technologies from 1900 to 1950, is that there are lots and lots of different devices. Not just different brands of devices, as we have today, but lots and lots and lots of different devices, each one designed to solve a very particular problem.[1]

What today we would characterize as data or information was recorded and stored differently then. It was either written down, mechanically inscribed, printed or typed out onto paper or some other medium. There were technologies, as we all know, for recording and storing sound (phonograph and audio tape), images (photographs) and moving images (film), as well as text (printing). The move to digital computing enabled the direct storage of data and information as well as a permanent record of all communication. Big data only became possible with the move to digital.[1]

Today, especially since about 2000, we are living in a world where information technology is distinguished by *convergence*. So what does this mean? Almost all our digital computers work in more or less the same way. Though there are many small differences between computer chips, their instruction sets and certainly between operating systems, all these digital devices work by the same basic set of processing principles and with very similar architecture. There are special-purpose chips for specific applications, but these too work by very similar principles. Add to this that our devices, because they are universal processors, can be used to emulate almost any systematic technological process; our current devices do the work that hundreds of devices did previously.[1]

Consciousness as Integrated Information Theory (IIT)

Space precludes me from outlining in detail Integrated Information Theory (IIT) so the abstract to the principal paper will have to suffice:

> The integrated information theory (IIT) starts from phenomenology and makes use of thought experiments to claim that consciousness is integrated information. Specifically: (i) the quantity of consciousness corresponds to the amount of integrated information generated by a complex of elements; (ii) the quality of experience is specified by the set of informational relationships generated within that complex. Integrated information (Φ) is defined as the amount of information generated by a complex of elements, above and beyond the information generated by its parts. Qualia space (Q) is a space where each axis represents a possible state of the complex, each point is a probability distribution of its states, and arrows

> between points represent the informational relationships among its elements generated by causal mechanisms (connections). Together, the set of informational relationships within a complex constitute a shape in Q that completely and univocally specifies a particular experience. Several observations concerning the neural substrate of consciousness fall naturally into place within the IIT framework. Among them are the association of consciousness with certain neural systems rather than with others; the fact that neural processes underlying consciousness can influence or be influenced by neural processes that remain unconscious; the reduction of consciousness during dreamless sleep and generalized seizures; and the distinct role of different cortical architectures in affecting the quality of experience. Equating consciousness with integrated information carries several implications for our view of nature.[2]

The theory offers a mathematical formula to compute a numerical value Φ which represents "the amount of information generated by a complex of elements, above and beyond the information generated by its parts." It seems that this Φ value is now the 'integrated information' and this determines the 'quantity of consciousness'. We then have 'quality of experience' which is "specified by the set of informational relationships generated within that complex." It is well known that different regions of the brain consist of a group of neurons that are specific for the generation and transmission of a precise piece of information, and it may be assumed that within those regions only a certain number of neurons will be firing. Take the so-called language regions of the brain for example.

According to the Wernicke-Geschwind model two principal regions in the brain involved in language are Wernike's and Broca's areas. Wernicke's area, located in the posterior temporal lobe near the auditory cortex, seems to be an important receptive center for language, while Broca's area, on the left side of the frontal lobes, seems to be an important language production center. Other brain areas have been found to be involved in language, including the thalamus and the basal ganglia. Also, the cingulate gyrus seems important for word retrieval, mainly because of the central role it plays in the directing of attention to the task at hand. The anterior superior temporal gyrus, which is located directly in front of the primary auditory cortex, is involved in word and sentence comprehension: it has numerous connections with hippocampal structures that are involved in memory. These recent results also confirm that the classic Wernicke-Geschwind model is far too simple and that language is a process much more distributed across many parts of the brain. This raises the additional new difficulty of trying to understand how so many different, independently functioning structures could have evolved in tandem to produce the synchronized activity necessary for language.[3]

So what then is IIT telling us about the 'quantity of consciousness' and 'quality of experience' of two friends seated in a café catching up on old times over a cup of coffee. At any one moment certain specific neurons would be firing in their brains in the following regions: autonomic nervous system, lower regions responsible for arousal, sensory areas for all five senses, proprioceptive region, thalamocortical loop, motor regions, memory regions, language regions, mood and emotion regions and widespread and diverse activity over the entire cortex. All of this information is simultaneously integrated as a holistic conscious event. Are we expected to accept that the quantity of consciousness and the quality of experience is dependent on the amount of information that is generated as a numerical value over and above the specific information transmitted from all those disparate regions. And are we expected to accept that the quantity of consciousness and quality of experience will be numerically different for these two individuals than for any of the other 7 billion humans on this planet. The quality of experience will certainly be different for different individuals, dependent on neurons specific for intelligence, wit, gregariousness, affability, emotion, sense of humor etc, but it is difficult to see how this could ever be quantified. And it's not readily apparent why this should even be included in an objective measurement of consciousness per se. Quality of experience is surely subjective and is socially, culturally and racially dependent.

Two recent research papers highlight the fundamental problem with explaining consciousness using fMRI scans to identify the regions of the brain that are active during any particular task or activity. Functional MRI measures blood flow as a proxy for brain activity. It shows where blood is being sent in the brain, presumably because neurons in that area are more active during a mental task. The problem is that the level of activity for any given person probably won't be the same twice, and a measure that changes every time it is collected cannot be applied to predict anyone's future mental health or behavior. This indicates that objective physical brain activity does not actually correlate with subjective states of consciousness.[4] And there is the added problem that a fMRI scan reveals the regions of the brain that are simultaneously active. How these disparate and often widespread regions of the brain can communicate instantaneously to generate a holistic consciousness is left completely unexplained.

Another research paper purports to answer the question what goes on in the minds of programmers when they write software. Again using fMRI scans it was found that programming is like talking. They found out that the brain regions that are most active are those that are also relevant in the processing of natural language and that speech understanding plays a central role in computer programming. Presumably then if a Φ value could be calculated it would be the same for a computer programmer and for a person engaged in a social conversation and yet subjectively the 'quality of experience' is entirely different.[5]

The communication of information within the brain generates 'shapes' in qualia space:

> Qualia space (Q) is a space where each axis represents a possible state of the complex, each point is a probability distribution of its states, and arrows between points represent the informational relationships among its elements generated by causal mechanisms (connections). Together, the set of informational relationships within a complex constitute a shape in Q that completely and univocally specifies a particular experience.

We note that this 'space' is purely theoretical, it is not to be found in a biological substrate, and it defies the laws of physics in as much as it is infinitely dimensional. On a practical level the language areas of the brain would constitute a complex within the meaning of IIT so in order for a human to say the sentence "The cat sat on the mat" this would involve the communication of information from the entire complex that generates a shape in Q that 'completely and unequivocally specifies' that 'experience'. I don't know how many synapses would have to fire in the language areas to generate this information, and nor does the author of IIT, but for argument sake let us say a billion. And for argument sake let us say another 10 billion synapses throughout the brain fired simultaneously that generated the consciousness of the person having this 'experience'. So does that mean an 11 billion dimensional space was generated in Q that 'completely and univocally specifies' that 'experience'? Apparently not. Because the Φ value is responsible for the shape in Q and this is the information over and above the actual information generated by those 11 billion synapses. It seems that all this information in order to become 'integrated' and generate the quantity of consciousness and quality of experience in the form of a shape in Q has to go through some kind of filter or further processing but IIT is completely silent on what where how and whys of this filter.

On a philosophical level Q and the shapes generated therein are even more problematical. For a start it revives the debate that has raged over the millennia about Plato's ideal forms. Q sounds very similar to the realm of forms and the shapes in Q come across as abstract perfect unchanging concepts or ideals that transcend time and space. They do differ from Plato's forms in as much as they don't represent the ultimate reality of the experience although they do 'completely and univocally specify' the experience. No these shapes are extremely complex and unfathomable probability distributions about the state of the complex generated by the Φ value which is integrated information over and above the information generated by all the complexes. So they certainly differ from Plato's forms in as much as they are clearly not unchangeable. In fact to determine our conscious 'experience' they must be in a continuous state of flux. Which begs the question – Is it even meaningful to calculate the probabilities that a complex is in a particular state if it is in fact in a continuous state of flux?

Another philosophical question is how does Q differ from Descartes' mind. Is not Q a ghostly ethereal unextended concept that IIT claims to be located in our material body, although not attached to it and not dependent upon it. How does an infinitely dimensional qualia divorced from earthly time and space that represents the probabilities that all the subgroups and complexes of neurons and synapses in our brain are in a certain state differ from our 'soul'? Has not IIT simply given the ghost in the machine a different name?

IIT attempts to avoid this question by drawing a very strong analogy between the human brain and a digital computer. Clearly these days nobody would suggest that our PC is anything other than a machine whose operations can be fully explained in terms of encoding and processing media. Here I stress 'digital' computer and not 'analog' computer because this notion of encoding media occurred precisely with the move from analog to digital computing and communications. Integrated Information Theory is a child of the information age. The fundamental rationale of IIT rests on the information theory of Claude Shannon.

Digital code, the ons and offs that are stored on your hard drive, USB pen or, if you still have some, your DVDS, are unreadable to humans in their digital state. That seems obvious enough. The encoding of the information and the processing instructions are not meant to be read by any person. They are meant to be read by a mechanism that processes them and presents us with something that we can read, view or interact with that is meaningful to us as human beings.[1]

Shannon was working on the Differential Analyzer at MIT. In his MA thesis he was able to show how you could develop algorithms for solving problems using circuits of relay switches. Then he noticed that the calculus he had developed was almost identical to the Calculus of Propositions developed in the 1840s and '50s by the English mathematician George Boole. He recognized that circuits, made up of relays (on and off switches), could be organized so that they could solve algorithms – that they could be programmed to make decisions. That the ons and offs of the relay circuits could be understood, in mathematical logic, as trues and falses.[1]

During WWII Shannon was working on cryptography (codes and code breaking). His work on code-breaking centered mostly on the problem of redundancy in language. All languages have redundant bits, such as the u that always follows a q in English. The u is not necessary at all, but is always included. We do not necessarily need to use the word the, but we do as both a convention and to refine meaning. These are examples of redundancy.[1]

For code-breakers it is the redundancy of language that allows them to find key patterns in a code so it can be broken and Shannon was able to quantify how much redundancy needed to be removed from a message to make it unbreakable. He did this by associating the reduction of redundancy with the amount of 'noise' in a channel – the amount of interference on a communications channel that makes it hard to interpret the original message. While working on cryptography, Shannon was also working, on his own, on the concept of 'information', or, as he originally characterized it, 'intelligence'. This eventually led to an 'optimum code' that would allow the maximum amount of 'intelligence' transmitted over a line when the number of signal elements (letters, numbers, symbols) was known. It became unnecessary to consider what the actual 'meaning' of a message was, but that what mattered was to determine how to transmit the message at the maximum speed with minimal distortion.[1]

The optimum code is of course digital based on the binary number system where each digit represents a power of 2 (4, 8, 16 etc). The first 5-bit binary code was developed to replace the Morse code for telegraph systems and at that stage it could actually be read by skilled operators. That is to say it had meaning for human beings. Because encoding and decoding of digital messages could be mechanized, the Baudot–Murray code became the only mechanized encoding of telegraph messages by the 1920s. With mechanization and the switch from analogue to digital computers the 'information' was now encoded and no longer had any meaning for humans. This is the essential difference between analog and digital devices.[1]

I thought it necessary to give some detail about how information theory came about, for in the paper on IIT we encounter the following statement:

> Information is classically defined as reduction of uncertainty: the more numerous the alternatives that are ruled out, the greater the reduction of uncertainty, and thus the greater the information. It is usually measured using the entropy function, which is the logarithm of the number of alternatives (assuming they are equally likely). For example, tossing a fair coin and obtaining heads corresponds to

> log2(2) = 1 bit of information, because there are just two alternatives; throwing a fair die yields log2(6) = 2.59 bits of information, because there are six.[2]

IIT asks the question what is the difference between a conscious human being and a photo-diode that is a simple sensor device that will turn on if it senses light above a certain threshold and will remain off otherwise – responds true or false to light. If this photo-diode is in front of a screen that is animated with light (it could be different colors or a movie or strobe lights or whatever) the photo-diode will register a true to the presence of light whereas a human being will be able to determine what is causing the light and what is actually appearing on the screen. Essentially integrated information enables the human brain to process an infinite number or true or false results – essentially discounting all possible false results as to what is not appearing on the screen – and arrive at a true result as to what is appearing on the screen. So the brain is essentially an integrated circuit processing digitally encoded binary information via logic gates – true or false.

> According to the IIT, the difference has to do with how much information is generated when that distinction is made. Information is classically defined as reduction of uncertainty: the more numerous the alternatives that are ruled out, the greater the reduction of uncertainty, and thus the greater the information… it is all this added meaning, provided implicitly by how we discriminate pure light from all these alternatives, that increases the level of consciousness.[2]

Now what is the difference between a conscious human being and a digital camera whose sensor chip is a collection of a million binary photodiodes, each sporting a sensor and a detector. The camera's detectors could distinguish among $2^{1,000,000}$ alternative states, an immense number, corresponding to 1 million bits of information. According to IIT the difference is that the information is integrated to give humans a ‘point of view’ whereas the camera is just an array consisting of a million unintegrated trues or falses. Unlike with the camera our brain ‘integrates the information’ to give us a sense of self. How this integration actually operates and how it differs from our soul or our mind is left unexplained. Be that as it may, this is what determines our quantity of consciousness and the quality of our experience. It is this integration that converts all those trues and falses into a Φ value.

> Mechanistically then, underlying the unity of experience must be causal interactions among certain elements within the brain. This means that these elements work together as an integrated system, which is why their performance, unlike that of the camera, breaks down if they are disconnected.[2]

The Mathematics of IIT

We have seen that IIT is based on a mathematical value of Φ which is said to represent the quantity of consciousness as well as the quality of experience. A fairly complicated equation is presented which is said to measure the difference between the probability distribution generated by the system as a whole (p(X0(mech,x1)), the actual repertoire of the system x) with the probability distribution generated by the parts considered independently (Πp(kM0(mech,μ1)), the product of the actual repertoire of the parts kM). In the case of the human brain then we are talking about a probability distribution for the brain as a whole and the probability distributions for all the 'independent' regions of the brain multiplied together. Presumably the probability distribution for the whole brain means a numerical value for all the synapses in the brain that are 'on' at any one moment and the probability distribution for the 'independent' regions would be all the synapses in just that region that are 'on' at any one moment. The equation is silent on just how the difference between these two probability distributions is to be computed, although it is implied that the probability distribution for the whole brain will be 'greater' than the product of the probability distributions for the 'independent' regions and this 'excess' value of probability distribution is the Φ value.

Personally I have issues with many aspects of this theory. For a start I deny that it is possible to do a probability distribution for all the synapses in the brain that are 'on' at any one moment, and I deny that it is possible to do a probability distribution for all the synapses in the various regions of the brain that are 'on' at any one moment let alone multiplying them all together. I deny that it is even sensible to talk about the 'independent' regions of the brain in as much as they all connected into one network. I deny that it is meaningful to talk about the 'difference' between all these probability distributions. But these are just practical problems.

Eugene Wigner the Nobel Laureate in Physics wrote a paper "The Unreasonable Effectiveness of Mathematics in the Natural Sciences" where he marveled at how effective mathematics has been in enabling scientists to explain and predict natural events and processes. The areas of mathematics that he was particularly alluding to are the differential calculus, statistics and quantum mechanics. The operative words here is that mathematics enables an observing scientist to 'observe and predict' natural processes. In other words they can predict with mathematical formulas what 'probably' will happen with a great level of certainty. That's clearly not the case of course with IIT that we are considering here but in many cases mathematics has been extraordinarily effective in enabling an observing scientist with a measuring stick and a stop watch to collect numerical data that is charted into a Cartesian grid and arrive at a result of what will probably happen in the natural process under study in the future.

IIT however claims to go further than that. The title of the principal paper "Consciousness as Integrated Information" appears to be making the claim that integrated information is actually generating consciousness, that is to say that integrated information is a dynamic natural organic process. According to IIT synapses actually work out statistically what state they probably are in and then they form themselves into a probability distribution whether for the whole brain or for a particular region and then they plug themselves into a formula that computes the Φ value and consciousness is generated in us in exactly the same way that your laptop boots up when you turn it on. And this is not even taking into account that neural processes are continuous, and that consciousness is holistic so the brain is never in a static state. There are any number of reasons why this claim is absurd, not the least of which, is the fact that information theory is about encoding the message digitally, and numbers do not exist in Nature. It is simply nonsensical to talk of an organic brain calculating its own Φ value and then generating consciousness accordingly in some sort of a continuum. It is even more absurd to pretend that the brain is constantly computing this Φ value from moment to moment.

The Brain as an Analog Computer

A recent essay — "Solving the 'hard problem': Consciousness is an electronic phenomenon" argues that the action potentials (APs) of neurons occur as a result of electromagnetic processes.[6] Basically magnetite crystals also known as BMNPs (Biogenic Magnetic Nanoparticles) are ubiquitous in the brain and are superparamagnetic. This means that electric flux will magnetize them as will low frequency electromagnetic radiation (EMR) that acts upon them in exactly the same way as a magnetic field.[5] Magnetizing the BMNPs in turn generates magnetic flux which opens ion channels and enables current to flow thru the membrane of the neuron. The 'spikes' generated by action potentials are therefore mediated by this complementary relationship between electric flux and magnetic flux encapsulated in Maxwell's classical equations of electromagnetism. As these 'spikes' are actually an oscillating current along the axon they will also emit radio waves at the same frequency as the current. These radio waves are universally referred to as brainwaves which likewise can magnetize the BMNPs and initiate action potentials elsewhere in the neural network.

A new research paper has detected never-before-seen waveforms in the dendrites of the pyramidal neurons in the cortex of the brain.[7] The paper argues that these waveforms are mediated by neurotransmitters in the synaptic gaps which regulates the electric flux caused by the flow of calcium and sodium ions which actually modulates the amplitude and frequency of the 'spikes'. Up to now the spikes of action potentials were thought to be typical all-or-none flow of sodium ions as the action potential propagates along the axon and were not graded in any way but this new finding indicates that in the neurons of the cortex at least, the spikes are creating waveforms that vary in amplitude and frequency in such a way as to suggest that the brain is performing logical processing similar to a computer or a Turing machine. It is argued that the capacity of these spikes to generate brainwaves of a varied amplitude and frequency that can communicate information elsewhere in the neural network indicates that the brain is not a classical computer or Turing machine, but is in fact an electronic device.

As numbers don't exist in Nature it is clear that the communication of information in an organic brain can not be digital. Messaging in the brain cannot be encoded. It is equally clear that electromagnetic radiation (EMR) does exist in Nature and that it can communicate information at the speed of light. Brainwaves are extremely low frequency (ELF) radio waves, that is to say they are at very bottom of the EMR spectrum and it has now been settled beyond doubt that brainwaves do in fact convey information.[9,10,11,12] This indicates that the neurons in the brain are 'hard wired' to perform specific functions and the sequence of neurons that fire actually emits a precise waveform that is received by other neurons elsewhere in the neural network so information is conveyed at the speed of light to enable further processing towards generating a continuous holistic consciousness that incorporates input from manifold regions in the brain. In other words the brain is an analog computer where the messaging is natural, direct and not encoded in any way.

Conclusion

Currently one of the leading explanations for consciousness is Integrated Information Theory (IIT) that attempts to give a mathematical value for consciousness based on statistics and probability distributions. IIT has evolved considerably and the mathematics offered to explain how consciousness is 'caused' or 'generated' has become very sophisticated indeed involving the differential calculus, matrix mechanics and the probability theory in quantum mechanics.[13] What these theorists fail to realize is that all of mathematics in the natural sciences is hypothetical, theoretical and essentially statistical. Take for instance the crown jewel of mathematics in the natural sciences, the differential calculus. The simplest differential equation to calculate the velocity of a natural body simply computes the average speed of that body between two points on a hypothetical Cartesian grid. It says nothing about the actual speed of that body from moment to moment. Again the simplest integral only tells the observing scientist the area under the curve on a Cartesian grid. Real objects operating in natural processes don't differentiate themselves or integrate themselves or do statistical probability distributions to ascertain what 'state' they are currently in or what 'state' they are likely to be in at some time in the future. Mathematics is obviously a valuable tool for observing scientists who seek to explain and predict natural processes but is says nothing about the actual forces that are actually driving those natural processes. In the last resort mathematics is merely descriptive and not dynamic. The IIT in attempting to explain consciousness mathematically as if the brain were a digital computer is way off the mark.

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