THE UNREASONABLE EFFECTIVENESS OF MATHEMATICS: CARTESIAN LINGUISTICS, THE MIND-BODY PROBLEM AND PRAGMATIC EVOLUTION

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Introduction

Victor Gomez-Pin highlighted succincty one object of the second Congress on Ontology held in San Sebastián and Barcelona in March of 1996 —by raising two questions due to Husserl about Descartes, namely: is there a persistent value to Descarte's most basic ideas? And if so, can they stimulete new, powerful ideas in our era? Indeed, one of the most interesting and fundamental puzzles that Descartes was the first to face with any success is the nature of the connections between mind and body, and the relevance of mathematics to both. It was the physicist Eugene Wigner, however, who called it the "unreasonable" effectiveness of mathematics, by which he had in mind above all the powerful applications of mathematics to physics, which have proven crucial for the advance of modern science.[1] The Greeks showed and early interest in these most basic questions of ontology and epistemology, and from the answers given by such figures as the Pythagoreans and Plato in antiquity, it is clear that mathematics played a fundamental part in their analysis and understanding of nature. Two millenia later, Galileo described his own similar point of view as follows:

> [The book of Nature] is written in the language of mathematics, and its characters are triangles, circles and other geometric figures without which it is humanly impossible to undestand a single word of it; without these, one wanders about in a dark labyrinth.[2]

Nature is mathematical, or may be explored and understood mathematically, because mathematics is the language of nature. But if so, this immediately suggests another question: where does the language come from? Galileo believed that the world was created using mathematics —and as far back as the Greeks, it was assumed that the universe was constructed according to the ratios and proportions of geometry, that all of nature proceeds therefore according to number, weight and measure:

> Nonetheless, the approach taken here in exploring the question of why mathematics should be so effective in the exploration of nature is somewhat different from Galileo's. Going back to the title, "The Unreasonable Effectiveness of Mathematics: Cartesian Linguisitics, the Mind-Body Problem and Pragmatic Evolution," the mention of "Cartesian Linguistics" is a reference to ideas associated with the linguist Noam Chomsky, the "Mind-Body Problem" recalls immediately the philosopher Descartes, and "Pragmatic Evolution" is associated with the father of Prgamatism, Charles S. Peirce. Each of these, as will become apparent, is specially relevant to the subject of this study devoted to ontology in general, but to Descartes in particular — and above all, to the questions considered in the following, mamely questions about mathematics and the reasons why it has proven so powerful in the study and explication of nature.

In what follows, attention will be devoted primarily to the American father of Pragmatism, Charles S. Peirce, to a brief history of neurological understanding of specific aspects

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[1] Wigner 1960.

[2] Galileo 1623, quoted from Drake 1957, p.238.

of the mind-body problem, which may be traced back to many ideas pioneered by Descartes, and to the claims of Cartesian linguistics championed by the linguist Noam Chomsky. In part, much here will be sketched very broadly —to provide more historical context than detail, especially where issues of bio-physics, chemistry and neuro-anatomy arise— much of which we owe to the pioneering studies of the Spanish Nobel laureate Ramón y Cajal. But first, what does any of this have to do with the American logician/philosopher, Charles S. Peirce?

Charles Peirce, abductive logic and the evolutionary history of the brain

One of the stories Charles Peirce liked to tell about himself involved the theft of a valuable gold watch and his subsequent conjecture about the identity of the thief, a conjecture that turned out to be something more than a lucky guess. Peirce delighted in recounting his dramatic hunt for the stolen goods, and his great relief when they were ultimately recovered. The theft occurred on a trip Peirce made to New York City aboard a coastal steamer, the *Bristol*, where an expensive Tiffany watch and fob, along with his coat, were taken from his stateroom.[3] Peirce insisted on lining up the entire ship's crew in an effort to identify the culprit who had taken the watch. As Pierce vividly described it:

> I went from one end of the row to the other, and talked a little to each one, in as *dégagé* a manner as I could, about whatever he could talk about with interest, but would least expect me to bring forward, hoping that I might seem such a fool that I should be able to detect some symptom of his being the thief. When I had gone through the row, I turned and walked from them, though not away, and said to myself, "Not the least scintilla of light have I got to go upon". But thereupon my other self (for our own communings are always in dialogues,) said to me, "But you simply *must* put your finger on the man. No matter if you have no reason, you must say whom you will think to be the thief". I made a little loop in my walk, which had not taken a minute, and as I turned toward them, all shadow of doubt had vanished.[4]

Lather, Peirce described this incident in detail to his friend, the Harvard philosopher and phychologist William James (1842-1910).[5] He did so because he had come to regard the story as an excellent example of what he called the logic of abduction. He also described this as the "inclination to entertain an hypothesis", which served to explain "why it is that people so often guess right". This in turn was intimately connected with Peirce's philosophy of science, for he viewed abduction as the key to understanding the nature of scientific knowledge and how it is obtained. Peirce described the formation of a hypothesis as "an act of insight", the "abductive suggestion"coming tu us "like a flash".[6] There was another principle at work as well, one re-

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[3] The version presented here is derived from Peirce's own manuscript account, "Guessing", Houghton MS CSP 687. This manuscript actually contains two different versions of the story, separately paginated, the earlier in a clearer hand, the other (presumably later) in a less steady hand, but with more detail. The story was first published (as his papers were being readied for publication) in a Harvard University magazine, *The Hound and Horn*, Peirce 1929. It is also mentioned briefly in Peirce 1958, 7, 7.36-48. Recently, another account of the story was given by Sebeok and Umiker-Sebeok 1979. This article has been reprinted in Sebeok 1981, pp. 17-21; and in Eco and Sebeok 1983, pp.11-54. For a recent account of the story, see Dauben 1989 and 1996; note that Dauben 1996 actually represents a revised version of Dauben 1989; Dauben 1996 also contains a greater number of illustrations than appear in Dauben 1989.

[4] Houghton MS CSP 687, pp. 10-11; also in Peirce 1929, p. 271; quoted in Sebeok and Umiker-Sebeok 1979, as printed in Eco and Sebeok 1983, pp. 11-12 (the transcription is not entirely accurate).

[5] James encouraged Peirce to submit an account of this episode for publication in the *Atlantic Monthly*. He did so, but the piece was rejected by Bliss Perry, the Monthly's editor. The story was not printed until it was given to *The Hound and Horn* in 1929. See Sebeok and Umiker-Sebeok 1979, as printed in Eco and Sebeok 1983, p. 48, note 3.

[6] Peirce 1931, vol.5, 5.181, and Peirce 1958, vol. 7, 7.39-40, 7.46, 7.218-219, and 7.679.

flected in a maxim made famous by the fictional detective Sherlock Homes, who was always guided by the "old axiom", as Peirce called it, "When all other contingencies fail, whatever remains, however improbable, must be the truth."[7]

The point of this story about Peirce and the pragmatic reasons he gave for why we so often "guess right", how it is all related to his theory of abduction, to mathematics, and to the mind-body problem, will become clear after we turn o what may at first seem an entirely different subject — namely our understanding of the nature of thought, and the neuroanatomy of the brain. The subject has a long and fascinating history of its own stretching from Aristotle to Descartes and, in its modern development, to careful histological studies of Ramón y Cajal and the more recent understanding of localization of cortex functions culminating in the research of Wilder Penfield and his colleagues in Canada.

René Descartes and the human brain

René Descartes published the Latin version of his study of human anatomy and physiology, *De homine*, in 1662, followed by a version in French in 1664.[8] In working out a materialist biology in considerable detail, Descartes explained his theory of brain function in clear, graphic, mechanistic terms. To account for vision, for example, he explains that light from a material object ABC enters the eye where visual images are projected onto the retina, which in turn is connected to the brain via the optic nerve. Sensing pressure on the back of the eye, the brain then relays this information to the pear-shaped pineal gland, where Descartes assumed the image *abc* was formed in the mind as a direct result of this mechanical series of relays conveying the physical information from ABC to the mind's copy or mental image *abc*.

Having received the optical message transmitted by means of what Descartes called "animal spirits" to the pineal gland, this in turn initiates an appropriate reponse or motor stimulus. Thus animal spirits from the brain are conveyed through a nerve to the arm muscle which then inflates, producing the intended motion. Although Descarte's explanation is rather crude in its way, the modern theory of reflex action may be said to begin with his primitive concept of afferent and efferent components.[9]

Santiago Ramón y Cajal (1852-1934)

What Descartes was in no position to appreciate was the importance of the brain's micro-structure, its neural anatomy, nor did he elaborate a sufficiently detailed theory of brain localization. As for the brain's neuro-anatomy, Santiago Ramón y Cajal once described the nerve cell as "The aristocrat among the structures of the body, with its giant arms stretched out like the tentacles of an octopus to the provinces on the outside word, to watch for the constant ambushes of physical and chemical forces".[10] It was Ramón y Cajal who discovered in 1871 that neurons could be selectively stained with a special silver preparation. Although the method picks out only one in a hundred cells, it monetheless stains the entire neuron body, along with all its processes, thus setting it apart for easy examination.

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[7] This maxim is announced by Holmes in the course of a remarkable story involving stolen plans for the Bruce-Partington submarine, top-secret at the turn of the century, which first appeared in Doyle 1908. It is reproduced in Baring-Gould 1967, vol. 2, pp. 432-452. See esp. p. 446.

[8] Descartes 1664, Fig. 53; reproduced in Clarke and Dewhust 1972, p.69, Fig. 93.

[9] Clarke and O'Malley 1968, pp. 329-333.

[10] Restak 1984, p.24.

Each of the ten billion neurons in the human brain may have over a thousand synapses, the points of contact between nerve cells. For some cells in the cerebral cortex, the numbers may approach two hundred thousand such connections. Thus the total number of connections within the vas extent of the human brain's neuronal system is truly astronomical —greater than the number of physical particles in the known universe.[11] Given such complexities of neural-network structure, how can behavior or function be correlated with specific parts of the brain?

Cortical localization

Modern advances in the study of cortical localization have been made by numerous neurologists, but perhaps no one has been more influential in this regard than Wilder Penfield, working in Montreal, Canada. Through direct electrical stimulation of the cortex in fully conscious patients, he and his colleagues have been reponsible for constructing remarkable "homunculus maps" of both the sensory and motor areas of the human brain.

By applying a threshold current to various excitable areas of the cerbral cortex, a variety of responses folow which may be broadly categorized as motor,sensory and metal, pertaining to the brain itself.[12] For example, sometimes electrical stimulation of a sensory area results in a basic sensation of seeing, hearing or feeling, depending on the site. Somatic sensations include such subjective feelings as tingling or a sense of movement, visual responses include a sense of moving lights, colors, or stars, whereas auditory phenomena may include a perception of buzzing, whispering, singing or thumping sounds. Similarly, stimulation of motor areas results in a wiggling of toes, fingers, a twitch of the mouth —even salivation, chewing, and swallowing. To determine the exact order and relative extent of cortical areas that can be identified in either the sensory or motor sequence, Penfield and Boldrey created vivid, graphic maps that have come to be known as the sensory and motor homunculus.[13]

Other neurologists have also contributed to our growing understanding of brain function using allied but complementary means. For example, studies of brain lesions have been used to locate regions associated with impaired abilities, enabling identification of areas for long-term memory as opposed to short-term memory, as well as areas designated for number and melody.

Micro-structures and neuro-anatomy

While macro-structure anatomy of the sort perfected by Penfield and his colleagues has led to increasingly refined understanding of the brain's topology, studies of the micro-structure of neurons and neuro-anatomy have been equally significant. Here one of the major problems in cortical histology has been the nature of the connections and interaction between an axon and the cell to wich it discharges its impulses. At issue, in part, was whether they were actually connected or not. For example, Ramón y Cajal in the last paper he published discussed the matter in some detail, conluding that "the dendritic spines are not connections between axon and dendrite.... Nevertheless, the fact remains that the axons approach the dendrites very closely".[14]

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[11] Restak 1984, p. 27. The brain's growth and final form depend on brain cell multiplication, a process that races on during the mine months before birth at about 250,000 new neurons per minute.

[12] Clarke and Dewhurst 1972, p. 127. Of Penfield's voluminous writings the following have been used here: Penfield and Boldrey 1937, pp. 389-443; Penfield and Rasmussen 1957; Penfield 1968, pp. 831-840; and Penfield 1958.

[13] Penfield and Boldrey 1937, p. 432.

[14] Ramón y Cajal 1934, p. 16.

Remarkably, it was not until the 1960s that silver staining techniques succeed in revealing the entire reticular formation of neurons. And as late as 1978 the neurologist Charles Needham could still observe how remarkable it was that "knowledge ot the structural organization of the thalamus... is virtually limited to the work of Ramón y Cajal (in 1900 and 1911)."[15]

As for the actual "wiring" of the human brain suggested by the techniques pioneered by Ramón y Cajal and Golgi, Needham explains:

The neurons of the human brain have inputs and outputs organized in parallel. in series, and in circuits... The number of synaptic contacts between one neuron and other neurons in the human brain is ordinarily between 1,000 to 10,000. As many as 30,000 synapses can occur in a single reticular neuron. There are more than 10 billion neurons in the human cerebrum and something on the order of 10-100 trillion synapses.[16]

If synaptic connections are conceived of as on/off gateways, where information is either blocked or allowed to pass, this information may be represented digitally as either 0 (blocked) or 1 (passed). From this point of view, there are obvious direct analogies with computer circuitry. If one looks at an entry in the stored memory of an electronic computer, say:

0011010001011011...,

this could represent, without additional information, numbers, letters, words, part of a musical score, a graphic design, even a photograph or a simple Morse code. Indeed, with nothing more than 0 and 1, a binary code could represent any of these, and of course the possibilities are endless.

In addition to objects, binary code can also convey instructions. Computers have been programmed to write poetry, play chess, and administer psychotherapy.[17] JOHNNIAC was even designed to prove propositions of Russell and Whitehead's *Principia Mathematica*. The extraordinary power of binary encoding also lies behind the structure of neural networks. As Needham puts it:

> If one examines the axonal output of an individual neuron, one also discovers a binary series of the action potentials and intervening non-action potentials...
> i.e. 0011010001011011... .

In other words, either the axon fires an impulse capable of bridging a synapse, or it does not. It either makes a connection (1) or it does not (0). Here the analogy between synapse networks and the digital computer is direct.

Needham summarizes the significance of all this, neurologically, as follows:

> The all-or-nothing behavoir of the inidividual neuron is the elemental unit of logic. All language are reductible to logic. All mathematic is reductible to logic... . If quantifiable order or logic is the substrate for both mathematics and language, what is the final substrate for logic itself? How is logic generated?

Logic has strictly biological origins. The rapid processing of information favors survival. The opposite favors extinction... To say that all logic originates in living nervous systems is to redefine logic. Original logic is always bio-logic.[18]

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[15] Needham 1978, p. 184.
[16] Needham 1978, p. 191.
[17] Weizenbaum 1976.
[18] Needham 1978, p. 193.

Neural networks, Needham stresses, are just like computers:

> Any processor of binary logic can be regarded as a digital computer, and this is the output property of the individual neuron. The stimulus or dendritic input to the neuron is the trigger which either depolarize the membrane potential to threshold and produces the axonal response of a single action potential (1) or fails to sufficiently depolarize so that no action potencial occurs (0).[19]

But the brain is not simply a digital device, an all-or-nothing zero-one processor, because when an action potential arrives at an axon terminal, a "transmitter substance" is released, *noradrenaline* or *dopamine*. Needham explains the further significance of this more subtle aspect of neuro-chemistry:

> The extent of dendritic depolarization is proportional to the concentration of transmitter substance released..., thereby transforming the impulse frequency (i.e. digital code) of the transmitting neuron into the magnitude of depolarization (i.e. analog code) of the recipient neuron.[20]

Needham concludes as follows:

> In summary, a digital computer deals with discontinuous quantities —it counts. An analog computer deals with continuous quantities— it measures.[21]
>
> In terms of neural structures and activity, this reduces to the fact that dendrites *analogize*, axons *digitalize*. In other words, "the neuron is not merely an on/off switch. Rather, the neuron is a complex analog/ digital computer transmitting ordered, or logical, information".[22]

Human logic, in many respects, is binary: yes/no, true/false, even/odd, high/low, all/none, and/or, if/then, etc. All of these polarities are clearly well-suited to the binary character of the neuron network. Nevertheless, there is only a limited extent to which analogies between the human brain and artificial intelligence should be pushed. As Needham under-scores:

> Neurological intelligence is originative, artificial intelligence is derivative. Neurological intelligence is always alive, artificial intelligence is always dead... . One computer may program another, and may even construct and repair and interpret another, but the original logical instructions, codes, languages and programs are generated in living nervous systems.[23]

Furthermore:

> Logic is a biological survival mechanism which accomplishes the internalization of the world. Logic is the environment which confers meaning on the environment. The flux of all that is indeterminate, random, and accidental in the external world is measured, counted, quantitated (sic) and made determinate by the logical process of living nervous systems.[24]

Logic, of course, is essential to the ability to learn, another fundamental aspect of intelligence. Colin Blakemore emphasizes the importance of the human capacity for learning as follows:

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[19] Needham 1978, p. 194.
[20] Needham 1978, p. 195.
[21] Needham 1978, p. 196.
[22] Needham 1978, p. 196.
[23] Needham 1978, p. 199.
[24] Needham 1978, pp. 199-200.

> The emergence of the capacity to learn is the triumph of evolution... A primary requirement of any animal is that it should be able to anticipate changes in its environment. Inherited reflexes contain a static description of the events of high probability in the past experience of the species, but learning allows each animal to add a stock of personal secrets to its description of the probabilities of the world. To anticipate the future is the ultimate goal of the evolution of the nervous system.[25]

In turn, Blakemore relates this directly with language:

> As with words, the structure of grammar reveals the machinery of the human mind... In his revolutionary theory of syntax, Noam Chomsky claimed that people have within them an innate, universal system of syntax which makes them competent to learn to understand and to generate speech. This knowledge is the prerequisite for any human language. It comprises the laws govern the formation of elementary sentences; these "deep structures" are propositional descriptions...[26]

Or, as Chomsky himself has explained:

> The central doctrine of Cartesian linguistics is that the general features of grammatical structure are common to all languages and reflect certain fundamental properties of the mind... The study of the universal conditions that prescribe the form of any human language is "*grammaire générale*". Such universal conditions are not learned; rather, they provide the organizing principles that make language learning possible, that must exist if data is to lead to knowledge. By attributing such principles to the mind, as an innate property, it becomes possibles to account for the quite obvious fact that the speaker of a language knows a great deal that he has not learned.[27]

At an even deeper level, however, what is "known" may be said to depend upon what nerve cells communicate. Many animals, for example, have little or no sense of color. Others can see into that are invisible to us. As Colin Blakemore puts it:

> The brain gains its knowledge by a process analogous to the inductive reasoning of the classical scientific method. Neurons present arguments to the brain based on the specific features that detect, arguments on which the brain constructs its hypothesis of perception.[28]

Mathematics, logic and neuro-anatomy

Needham, who has been especially concerned with connections between mathematics, logic, and neuroanatomy, begins with the premise that thoughts represent the formalization of factual states of affairs. Pure mathematics and symbolic logic may be regarded as formal processes. But the formal relations of mathematics also seem to be independent of actual objects, and hence, in their formal sense, independent of sense perception. Even if our knowledge of them is *a priori* rather *a posteriori*, in order to comunicate this mathematical knowledge, "common" or familiar "conversational" language has developed chiefly as a means of communicating possibilities. A "formal" language like symbolic logic, however, is meant to be much stricter, and is expected to include all propositons, tautologies, and contradictions. Because of its rigidly formal nature, pure mathematics is inherently different from familiar "conversational" language.

There must, therefore, be a difference in the manner by which the nervous system represents *a priori* information, the information of necessary formalations, from the representation

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[25] Blakemore 1977, p. 116.

[26] Blakemore 1977, pp. 133-34.

[27] Chomsky 1966, p. 59-60.

[28] Blakemore 1977, p. 91.

of *a posteriori* information, that which arises from perceptual experience. Certain forms of information, it then follows, must be built into nervous system without the direct, immediate participation of sense-experience. Such information is correspondingly formal. It is on the basis of such information that we are able to conceive universals, for example, when we perceive only individual particulars. In mathematics, we envision entire sets and classes although we see only members. Somehow, we are able to "know" the infinite, even though we only confront the finite in either the objective or subjective words of space and time, in the objects, events and phenomena (both physical and mental) that we may consider.

Language versus computation

There are numerous instances, based on neurological case studies, in which computational ability is disturbed whereas language comprehension is not. Because of the participation of perceptual processes in propositional structures and the absence of perceptual mechanisms in necessary structures, the neurological foundation for each must differ. What language and mathematics have in common is logic. What distinguishes language from mathematics, however, is neurological. Put briefly, the words or language used to communicate the things or states to the external world must be represented differently in nervous systems from the way in which numerical relationships between such things and states are handled neurologically.

As Needham puts it, "Symbolization is neurological representation... The world is internalized and formalized by the logic operative in nervous systems".[29] The world, in other words, is internalized and formalized by the logic operative in nervous systems.

Mathematical prodigies

Here the case of certain prodigies is instructive. The British neurologist Macdonald Critchley has written extensively about higher corical functions and *idiot savants*. Prodigious calculators, he concludes, actually use enhanced memory rather than mathematical skill. Of the many case he has studied, most rely on extensive memorization of tables. These can be quickly recalled, with the use of mnemonics, and by using cross-multiplications and simple short cuts, the results can be impressive. Several cases are of very special interest — one subject showed a clear preference for working with multiples of 16; another was especially good at using powers of 2. This suggests that some idiot savants may rely on the hardwiring of the brain working on a binary system or a base sixteen estension of a binary system that exploits the "all-or-nothing" phenomenon of neuronal firing.

Here the binary character of neurons is essential; i.e. they either fire or they do not. There may be multiple other neurons feeding input to the dendrites of a single neuron, but the firirng neuron either fires or does not. As a result, the comparison with transitor and computer function is in itself interesting. At present computers are strongest in their computational abilities. Is it possible that in the absence of all the sensory clutter in the real world, without any internal stimulations and distractions —in other words, if left to itself— the left parietal cortex would be an excellent calculator. It is at least possible to consider a model of the brain that works as a very complex multiprocessing binary computer. In such a model each neuron plays the part of a complex processing computer, but gives only a single response. It either fires or it

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[29] Needham 1978, pp. 55-56.

does not. A given neuron may link to thousands of other neurons; these in turn, depending on multiple other possible inputs, either fire or do not.

Mathematics and the brain

It may be that the first and most basic concepts of mathematics begin with the recognition of one's own identity as distinct from all other objects, which amounts to self-awareness. Self-awareness may in turn be understood as a kind of recursive thinking. On this view, computers may be said to be conscious in at least a very limited sense, but with only one or two additional levels of self-awareness, they could also be considered to be just as "conscious" as human beings. For example, a disk operating system (DOS) is aware of typed input and responds accordingly. When a computer is switched on, it first undertakes a series of internal checks to make sure that its memory is functioning properly. This process may be taken as fist-order or a very primitive level of self-awareness. If another level is added —a parallel— or sub-processor perhaps which monitors the disk operanting system or the internal checks it makes— and if on this higher level the computer where asked what "it", i.e. the computer, was doing, the computer would reply that "it" was either responding to DOS commands or making a series of internal checks. Adding yet another level of self-awareness —video cameras perhaps, with which the computer could view itself as distinct from other objects around it— imagine how the computer would then respond if queried, now able to report where it was in its evironment and what it was doing? Would this be consciousness?

Some argue that humans are not only aware of what they are doing, but are also aware that they are aware, and that it is precisely this that makes us "conscious". On the other hand, after a few layers of recursive awareness have been added, the level of actual self-awareness becomes meaningless, that is, it makes no sense to say that "I am aware that I am aware that I am aware that I am aware" is any more "aware" than some one or thing saying "... I am aware that I am aware that I am aware that I am aware". Therefore, with only a few levels of recursive awareness, the computer may well be said to be "self-aware", and perhaps just as much self-aware as any human being.[30]

I will not consider any further here the question of whether computers may be self-aware or not, but go to suggest that once a being is self aware, as with a computer recognizing itself as different from the objects around it, then in turn it can begin to recognize other objects as being separate and therefore "countable". From this self-realization —a sort of *cogito ergo sum*— the concept of numbers arises. In this case, the number concept is *a priori* in the sense that we cannot be aware of it unless we have self-consciousness first. The *a priori* nature of numbers may well be related to the evolutionary history of the structure of the universe, made up of conglomerates of atoms which by nature of the environmental separations around them lend themselves to being seen as individual countable objects by our consciousness, leading thereafter to higher and more complex structures.

The actual neuronal structure of the brain that account for counting is probably related to the logic in the "chaotic" organization of neural netwoks in the brain. Recent neuro-anatomical research has shown that neuronal hardwiring in the brain actually follows chaotic patterns, that is, although appearing to be random or chaotic, they actually follow fractal patterns according

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[30] For recent discussions of evolution, the brain and human intelligence, see Edelman 1987, Chalmers 1995, Chalmers 1996, and Blodk, Flanagan and Güzeldere 1996.

to the rules of chaos which determine neuronal wiring. This hard wiring is influenced by sensory stimulation during the first two years of life; without it, with no stimulation during that time, the hard wiring never develops. From then on, sensory stimulation affects the "weighting" of neuronal connections between neurons in the neural networks, probably by a process known as "long term potentiation".

All this means that the hard-wiring of the neurological networks in the brain, which occurs during the first few years of life, are crucial. Part of the hard-wiring in the left parietal cortex allows us to count based on a complex but essentially binary output neural network. Subsequently, a simple memory system makes it possible to accomplish basic arithmetic. *Idiot savants* simply make use of this capability to an unusually high degree.

With the capacity to count, mathematical abilities help to describe the real, external world. This external reality presents itself as discreet objects which lend themselves to counting. The leap from counting to the laws of physics may be formidable, but perhaps reasonable after all, and undeniably effective as the history of science makes clear.

There is a remarkable symmetry between the quantum nature of physics, which in its most reduced form involves countable particles which combine to make up the almost (and perhaps) infinitely complex universe, just as neurons concatenate to form the almost infinite number of neural connections within our own brains.

Conclusion

Ultimately, the integration of mind and body may all be referred back to the insights Descartes offered on the essential connection between *res cogitans* and *res extensa*. Even though Descartes may have been wrong about the pineal gland serving as a king of biochemical central processing unit, he was nevertheless correct in the major outline he offered, suggesting that our knowledge of the external world is ultimately and inextricably seated in the biology of the brain.

Peirce, pragmatism, and evolution

Charles Sanders Peirce, the American Pragmatist, realized that both the laws of nature and the structures of our brains -which find ever more ingenious ways of apprehending and interpreting nature's laws —were the products of evolution. This was ultimately the secret to the answer Peirce gave to his question about why we so often guess right? How had he managed to guess who had stolen his gold watch? Above all, why from all of the infinite possibilities is science able to isolate the most relevant factors necessary to provide ever more accurate scientific theories?

> The mind of man has been formed under the action of the laws of nature, and therefore it is not so very surprising to find that its constitution is such that, when we can get rid of caprices, idiosyncrasies, and other perturbations, its thoughts naturally show a tendency to agree with the laws of nature.[31]

Hence, the mind is able to apprehend nature because it is itself a result of the forces and relationships in nature that have been instrumental in its evolutionary construction at every

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[31] C.S. Peirce, "The Proper Treatment of Hypotheses (A Preliminary Chapter, Toward an Examination of Hume's Argument Against Miracles, in its Logic and in its History), "Houghton MS CSP 692; and "Hume's Arguments Against Miracles, and the Idea of Natural Law", Houghton MS CSP 873, transcribed in Peirce 1985, vol. 2, pp. 890-904, esp. p. 901.

step. This is exactly what Noam Chomsky suggested in sayind that by the time evolution had produced the brain of *Homo Sapiens Sapiens*, the modern human brain had been structured in an *a priori* way as a result of that evolution, creating in the process a template with certain taxonomic categories awaiting initialization.

Unfortunately, human knowledge is not *a priori* in the sense that we simply wake up one day speaking Chinese —or solving differential equations. What *is* given, and *a priori* in this sense, is the brain itself, its complex neural networks and its seemingly infinite potential to respond to successful learning accumulated over millennia. In the short term, the brain is constantly exploring new strategies leading to new models and possibilities for both investigating and justifying new knowledge, apparently without limit.

With proper training in the early years of childhood, the brain is responsive to language and to mathematics. In the absence of appropriate initial stimulation, however, those structures apparently atrophy and it soon becomes impossible to establish neural pathways. On the other hand, once in place, as the human brain begins to grow and develop, it eventually discovers the unexpected, perhaps unreasonable effectiveness of those structures to provide models —of language, of mathematics, and of spatio-temporal relations in general.

As Descartes said, *cogito, ergo sum*, but without the ability to perceive oneself, and in turn to distinguish the one from the many, the first steps towards numbering and the successive hierarchy of mathematics from the discrete to the continuous. from the finite to the infinite, would never have been taken, nor would they even have been possible.

BIBLIOGRAPHY

BARING-GOULD, WILLIAM S., ed.:1967. *The Annotated Sherlock Homes*. New York: Clarkson N. Porter.

BLAKEMORE, COLIN: 1977. *Mechanics of the Mind. BBC Reith Lectures*, 1976, Cambridge: Cambridge Universite Press.

BLOCK, NED J.,: 1996. *The Nature of Consciousness: Philosophical and Scientific Debates*, Cambridge, Mass: MIT Press. Owen Flanagan and Güven Güzeldere, eds.

CHALMERS, DAVID J.:1995. "The Puzzle of Conscious Experience", *Scientific American*, 273 (December), pp.80-86.

1996. *The Conscious Mind. In Search of a Fundamental Theory*, New York: Oxford University Press.

CHOMSKY, NOAM: 1966. *Cartesian Linguistics: A Chapter in the History of Rationalist Thought*, New York: Harper&Row.

CLARKE, EDWIN AND KENNETH DEWHURST: 1972. *An Illustrated History of Brain Function*, Berkeley: University of California Press.

CLARKE, EDWIN AND C.C. O'MALLEY: 1986. *The Human Brain and Spinal Cord. A Historical Study Illustrated by Writings from Antiguity to the Twentieth Century*, Berkeley: University of California Press.

DAUBEN, JOSEPH W.: 1989. "Peirce ant the History of Science", in *Peirce and Contemporary Thought. Philosophical Inquieres (Proceedings of the Plenary Lectures delivered at the Peirce Sesqui-centennial Congress, Harvard University, 1989)*, New York: Fordham University Press, 1995, pp. 146-195.

1996. "Charles S. Peirce, Evolutionary Pragmatism and the History of Science," *Centaurus. International Magazine of the History of Mathematics, Science and Technology* (Denmark), 38, pp. 22-82.

DESCARTES, RENÉ: 1664. *L'homme de René Descartes*, Paris: N. Le Gras.; trans. by Thomas S. Hall, Treatise of Man, Cambridge, Mass.: Harvard University Press, 1972.

DOYLE. ARTHUR CONAN: 1908. "The Adventure of the Bruce-Partington Plans", *Strand Magazine*, 36, pp. 689-705; repr. in Baring-Gould 1967, vol. 2, pp.432-452.

DRAKE, STILLMAN: 1957. Trans., ed., *Discoveries and Opinions of Galileo*, New York: Doubleday.

ECO, UMBERTO AND THOMAS A. SEBEOK, eds.: 1983. *The Sign of Three*, Bloomington: Indiana University Press.

EDELMAN, GERALD M.: 1987. *Neural Darwinism. The Theory of Neuronal Group Selection*, New York: Basic Books, Inc.

GALILEO GALILEI: 1623. *Il Saggiatore nel quale con bilancia esquisita e giusta si ponderano le cose contenute nella Libra astronomica e filosoficsa di Lothario Sarsi Sigensano (pseud.)...*, Roma: Mascardi; for an English translation of this work, see "The Assayer" in Drake 1957, pp. 229-280.

NEEDHAM, CHARLES: 1978. *Cerebral Logic*, New York: Charles Thomas.

PEIRCE, CHARLES SANDERS: 1929. "Gussing", The Hound and Horn, 2(3) (April-Junes), pp. 267-282.

1931. *The Collected Papers of Charles S. Peirce*, C. Hartshorne and P. Weis, eds., Cambridge, Mass.: Harvard University Press, vol. 1-6 (1931-1935).

1958. *The Collected Papers of Crales S. Peirce*, A. Burkes, ed., Cambridge, Mass.: Harvard University Press, vols. 7-8.

1984. *Writings of Charles S. Peirce. A Chronological Edition*, 2 (1867-1871), Bloomington: Indiana University Press.

1985. *Historical Perspectives on Peirce's Logic of Science. A History of Science*, C. Eisele, ed., Berlin: Mouton, 1985.

PENFIELD, W.: 1958. *The Excitable Cortex in Conscious Man*, Liverpool: Liverpool Univeristy Press.

1968. "Engrams in the Human Brain", *Proeedings of the Royal Academy of Medicine*, 61, pp. 831-840.

PENFIELD, W. AND E. BOLDREY: 1937. "Somatic motor and sensory representation in the cerebral cortex of man as studied by electrical stimulation", *Brain*, 60, pp. 389-443.

PENFIELD, W. AND T. RASMUSSEN: 1957. *The Cerebral Cortex of Man. A Clinical Study of Localization of Function*, New York: Macmillan.

RAMÓN Y CAJAL, SANTIAGO: 1912. *La fotografía de los colores; fundamentos científicos y reglas prácticas*, Madrid: N. Moya.

1937. *Recollections of My Life*, trans. E. H. Craigie; repr. 1966.

RESTAK, RICHARD M.: 1984. *The Brain*, Toronto/New York: Bantam Books.

SEBEOK, THOMAS A. AND JEAN UMIKER-SEBEOK: 1979. "You Know My Method': A Juxtaposition of Charles S. Peirce and Sherlock Homes", in *Semiotica*, 26, pp. 203-50; repr. in Eco and Sebeok 1983, pp.11-54.

WEIZENBAUM, JOSEPH: 1976. *Computer Power and Human Reason: From Judgment to Calculation*, San Francisco: Freeman.

WIGNER, E. P.: 1960. "The Unreasonable Effectivenes of Mathematics in the Natural Sciences", *Communications on Pure and Applied Mathematics*, 13, pp. 1-14.