Borges: a neuroscientific perspective

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ABSTRACT

Introduction. Jorge Luis Borges is one of the most important writers of the 20th century. As well as being one of the most widely studied authors by literary critics worldwide, his work has sparked special interest among scientists from a diverse range of disciplines, who have found in his writings a productive dialogue with their own investigation of reality. In some of his short stories and poems, Borges is ahead of his time, glimpsing scientific conclusions that were reached years later.

Objective. This study analyses links between Borges and neuroscience in two directions: Borges as a *reader* of texts in this specialty and Borges as a *precursor* of certain neuroscientific discoveries.

Material and methods. To address the first point, we reviewed both Borges' works and the books in his collection. Regarding the second point, we analysed the ways in which Borges' fiction foreshadows, in a sense, certain neuroscientific discoveries, for which we searched for reviews on the PubMed database.

Results. Borges was in fact a reader of neuroscience, if we interpret this term in a broad sense. These readings served as inspiration for some of his stories and essays.

Conclusions. Despite lacking formal scientific training, Borges' sensitivity as a reader and the speculative power of his work enabled him to anticipate ideas related to subsequent discoveries.

KEYWORDS

Borges, neuroscience, neurology, psychology, memory, spatial orientation, neurolinguistics

Introduction

In the words of Alejandro Rossi,[1] "to write about the oeuvre of Borges is to resign oneself to being the echo of some Scandinavian commentator or tenacious, erudite, enthusiastic American professor. It is to resign oneself, perhaps, to rewriting the 124th page of a doctoral thesis whose author may at the very same moment be defending it"; this assertion is less hyperbolic than it may appear. An Internet search yields more than two million academic theses dedicated to analysing the work of Jorge Luis Borges (Buenos Aires, 24 August 1899-Geneva, 14 June 1986). Many were written by scientists from various disciplines, for whom the work of Borges is a subject of interest for a number of reasons. To name a few examples, Rodrigo Quian Quiroga[2-4] studies the question of memory in some of Borges' works; Guillermo Martínez[5] addresses the writer's relationship with mathematics; and Alberto Rojo[6] reflects on the author from the perspective of quantum physics. This widespread interest in Borges across the scientific community is no coincidence. His

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literary work has a speculative power that allowed him, through his interpretation of the present, to hypothesise about what may come to pass in some of the *several possible futures*.[A]

For Borges, literature represents a particular form of utopia, a laboratory of the possible. It can be said that one of the "powers" of literature (to borrow the terminology of Robin Lefere[7]) is that it challenges us to think beyond the beaten path. Thus, this ability to stimulate thought, inherent to Borges' writing, may enable us to understand the lasting attraction of his work for readers trained in a range of scientific disciplines. The author's personal obsessions included the tricks of time; perhaps he would have been pleased to discover that in his writing, he appears to have been ahead of his own time, glimpsing conclusions reached only years later by scientists.

This article particularly focuses on the relationship between Borges' writing and neuroscience. To precisely characterise the objective of this study, we may depart from two questions: firstly, what did Borges read, and what texts related to what is today known as neuroscience might be identified in his reading and be traced in his work? And secondly, what neuroscientific subjects might we find in his work, from the perspective of the 21st century? Which of his hypotheses are relevant with respect to neuroscientific ideas and theories? Therefore, we will first discuss Borges as a reader of neuroscience, and subsequently describe his role as a precursor of certain subjects addressed by neuroscience, exploring how neuroscientists may read the work of this Argentinian writer.

Methods

Regarding the role of Borges as a reader of neuroscience, we reviewed his entire oeuvre, using tools such as the search engine developed by the University of Pittsburgh's Borges Center (https://www.borges.pitt.edu/finders-guide). We also consulted archives holding Borges' collection of books (the Mariano Moreno National Library [Argentina] and the library of the Jorge Luis Borges International Foundation). This search identified texts read by Borges that address subjects related to what is today known as neuroscience; these are discussed in part I of the results section of this article.

Borges' role as a *precursor* of neuroscience is linked to a question that has been widely studied and discussed[8]: are there elements in Borges' oeuvre that anticipate future developments in scientific theory? Responding to this question requires a degree of caution. Borges did not have formal scientific training, although, as we shall see, he was a *curious reader* who took great interest in subjects related to science, as well as philosophy and theology. As noted by Lefere, we must avoid the hyperbole of the idea that Borges knew everything and was able to *foretell* scientific developments that came to pass years later. Nonetheless, we propose that Borges can be seen as a *precursor* of certain scientific (and particularly neuroscientific) developments, in the same sense that he used the term in his famous essay "Kafka and his precursors."[8] In this text, the Argentinian author argues that precursors are always created retrospectively: certain texts written before Kafka's time today appear Kafkaesque because we read them from the perspective of Kafka. In this manner, we (retrospectively) propose that neuroscientific developments enable a *rereading* of Borges and that we may find in his work observations and foresight that become meaningful in the light of the consolidation of neuroscience. Borges did not divine the future; rather, his work presents a speculative power and a freedom of the imagination that allows him to postulate "interesting"[B] hypotheses without needing to justify them. This speculation functions not as scientific evidence but rather to stimulate the imagination of his readers. This stimulus appears to be echoed by certain scientific researchers. The Argentinian writer insisted that books have meaning not in themselves, but rather when they make contact with a reader.[C] Thus, we propose establishing such contact between the hypotheses expressed in Borgean texts and certain subsequent neuroscientific developments, which may allow us to characterise the author's role as a precursor.

[A]This formulation is taken from *The garden of forking paths* (1941): "I leave to several futures (not to all) my garden of forking paths."

[B]"You will reply that reality has not the slightest obligation to be interesting. I will reply in turn that reality may get along without that obligation, but hypotheses may not" (*Death and the compass*).[9]

[C]"What are the words laid out in a book? What are these dead symbols? Nothing at all. What is a book if we do not open it? It is nothing more than a cube of paper and leather, with pages; but if we read it something strange occurs; I believe that it changes every time" (*Borges oral: obras completas IV*. Buenos Aires: Emecé; 2005. El libro; p. 183).

Results

Part I: Borges, reader of neuroscience

> *Certainly there is nothing in the universe that does not serve as a stimulus to thought.*
> "Pascal," *Other inquisitions*[10]

Many writers have drawn on neuroscience (or what is understood today by this term) to imagine their works or characters, perhaps due to their own reading or to close experience with various diseases. For instance, we may consider depictions of madness in Cervantes or Shakespeare,[11,12] or Proust's reflection on memory throughout his work.[13] As we shall see, Borges may be placed in the same category, given the fact that he is known to have read some works that, as mentioned previously, are related to neurosciences; these are either cited in his own work or identified in the search of archives of books he owned.

Borges frequently cites or mentions various authors working in scientific disciplines or touching on related questions, even borrowing their ideas in his work. It should be stressed that, in Borges' work, this recurrent presence of scientific discourse does not entail a singular hierarchy: science in Borges does not represent *truth* or an ultimate, undisputed authority. Above all, it functions as a stimulus for ideas, analogously to the roles of poetry, philosophy, or theology, or the sight of an inscription in the street. In Borges, a science book, a newspaper clipping, or the works of Homer are meaningful on the same level. As mentioned above, this involves an elimination or relativisation of the hierarchy of discourses. A true "literary utopia," to borrow a phrase from Genette.[14]

Borges' personal library (which we were able to consult in the archive of the Jorge Luis Borges International Foundation), which holds hundreds of books, includes at least 35 books on various scientific disciplines: mathematics, physics, geology, geometry, etc. Among the nearly 500 books he donated to the National Library after working as librarian (which are currently at the Jorge Luis Borges Center for Studies and Documentation), we identified a further 11 books on science.[15] Most of these texts include handwritten annotations by the author, indicating active reading. For instance, in the back cover of a mathematics book in German (Colerus E. [1937]: *Von Pythagoras bis Hilbert: die Epochen der Mathematik und ihre Baumeister*), he wrote that "only whole numbers are of divine origin" (Figure 1).

From this review of Borges' works and archives, we selected four authors whom we consider the most relevant among those books that Borges consulted on the study of the mind: Gustav Spiller, William James, Bertrand Russell, and John Stuart Mill. Below, we highlight certain characteristics of their theories that the author drew on to challenge us to reflect about the world.

1. Gustav Spiller (1864-1940)

Spiller was a Hungarian writer who lived in England from 1885, and dedicated a considerable part of his life to thinking about mankind, in the fields of both ethics and sociology, although he also made contributions to psychology, for instance in the book *The mind of man* (1902).[16] The book, in which he attempts to list all the memories of his life, was read and annotated by Borges in 1927. Underlined passages in the book include the following phrase: "We forget most things. A large portion of our life is thus given to fixing and re-fixing the shadows of things."[16(p187)] Spiller's project to record an entire life is echoed several times in Borges, for instance in "Funes, his memory," "Matthew 25:30," "John 1:14," and "The Aleph," among others.

Borges cites Spiller on numerous occasions, for example in the essay "A new refutation of time" in his *Other inquisitions*,[17] in which he discusses a classic problem in neuroscience, the question of mind versus matter. This essay also reviews the ideas of David Hume, George Berkeley, and Herbert Spencer with regard to whether consciousness ("the I") is a function of the brain, or even *one more* function of the brain. Regarding this question, Borges[17] asserts that "there is not, behind the visages, a secret I governing our acts and receiving our impressions. We are, merely, the series of those imaginary acts and those errant impressions." The text ends with the following deservedly famous lines:

> Time is the substance of which I am made. Time is a river which sweeps me along, but I am the river; it is a tiger which mangles me, but I am the tiger; it is a fire which consumes me, but I am the fire. The world, unfortunately, is real; I, unfortunately, am Borges.[17]

From these words, we may infer that Borges' position is that man, his consciousness, and his brain are, in effect, one and the same. While the neural basis of consciousness is yet to be fully understood, nobody today doubts that it is a robust phenomenon that is intimately linked with brain

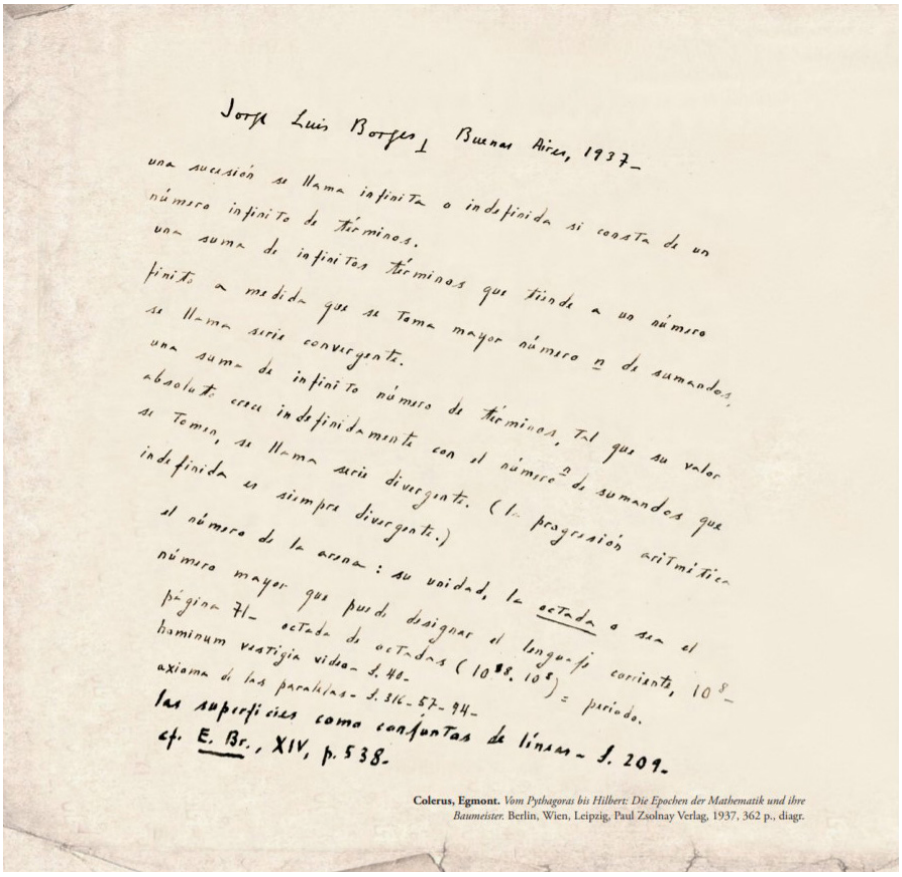

Figure 1. A page from a mathematics book, annotated by Borges (*Von Pythagoras bis Hilbert: die Epochen der Mathematik und ihre Baumeister, by Egmont Colerus* [From Pythagoras to Hilbert, the eras of mathematics and their masters]). Some of the notes read: "A succession is called infinite or indefinite when it comprises an infinite number of terms […]. The number of sand: its oneness; the myriad, or the largest number that can be expressed in normal language […]. The basis of arithmetic in Tlon is the notion of indefinite numbers.".

activity and has an important influence over behaviour.[18] This represents the first example of Borges intervening in a question with philosophical implications but which today represents a key theme in neuroscience, for reasons including the renewed attention of psychologists; rapid progress in the neuroscience of perception, memory, and action; advances in artificial intelligence; and a dissatisfaction with the dualist separation of mind and body. Identifying the neural basis of consciousness represents an even more relevant issue, which is known as the "hard problem" due to the difficulty of unravelling its solution. In any case, there can be no doubt of the relationship between consciousness (psychic or mental states) and the physiology of the brain.[18-22] Once more, Borges' position is situated on this line.

2. William James (1842-1910)

Another author Borges draws from is the Harvard psychologist and philosopher William James, elder brother of the writer Henry James. William was the founder of a current of psychology and philosophy known as pragmatism,[23] which in a broad sense purports that ideas are only correct insofar as they are related to other aspects of our existence.

The work of William James was particularly interesting to Borges, whose collection "Biblioteca personal" (Personal library), developed towards the end of his life, included one of James' major works, *The varieties of religious experience: a study in human nature* (1902), for which he also wrote a short prologue. In addition to this work,

Borges is known to have read *Pragmatism: a new name for some old ways of thinking* (1910) and *The principles of psychology* (1890)[24]: his archive contains both books, with numerous annotations (and drawings) by Borges and his mother Leonor Acevedo, who took notes for him when he lost his sight, preventing him from taking his own notes.

In *The principles of psychology*, James develops a motif that is revisited by Borges: the importance of forgetting, a central idea in his story "Funes, his memory,"[25] and once again in his poem "A reader."[26] The work by Izquierdo[27] is recommended for an excellent neuroscientific review on the *art of forgetting*. As a thorough examination of Borges' reading of James is beyond the scope of this study, we defer to Nubiola.[28] However, Borges' reading of this author demonstrates his general interest in questions related to neuroscience.

3. Bertrand Russell (1872-1970)

The philosopher, mathematician, and social critic Bertrand Russell received the Nobel Prize in Literature in 1950. In *The analysis of mind*[29] (which Borges read and annotated in 1933), one of his most influential books, Russell presents an intriguing reconciliation of psychology and physics or, in other words, between mind and matter. Among other subjects, he addresses memory, and particularly how memories can be distorted. As we know, remembering an event involves active construction of the past, or at least the parts of it that we are able to recall. The highly personal nature of this active construction explains how the same event may be recalled differently by people who experienced it at the same time. Through this process, it is possible to create false memories; indeed, the psychologist Elizabeth Loftus[30] demonstrated in the 1970s that false memories can be implanted experimentally. False memories have been studied by numerous other authors over the last 50 years, and it is known to be possible to induce false memory in laboratory studies through *1)* imagination inflation (repeatedly imagining events that never actually happened), *2)* false feedback (transmitting suggestive incorrect information in a conversation), and *3)* memory implantation (through doctored images or false statements from an individual's caregivers). This subject has been reviewed by Ulatowska and Sawicka,[31] Pardilla-Delgado and Payne,[32] and by Muschalla and Schönborn.[33]

Borges presents a very stimulating approach to this issue in "The creation and P.H. Gosse"[34] (*Sur*, 1941, collected in *Other inquisitions*), in which he recovers the ideas of Bertrand Russell. Philip Henry Gosse (1810-1888) was an English naturalist whose Christian fundamentalism prevented him from accepting the theory of evolution. In his essay, Borges explains the solution Gosse reached to respond to the dilemma that tormented Christians: the discovery of fossils. Dinosaurs are not mentioned in *Genesis*, and seemed to be the perfect argument to refute the Holy Scripture. Gosse's (incredible, irrefutable) response was that dinosaurs never existed. God buried fossils as a test of our faith. God meddled in and manipulated our vision of the past. In the essay, Borges compared Gosse's theory with Russell's idea about implanted memory:

> In the ninth chapter of his book, *The analysis of mind* (London, 1921), he imagines that the planet was created only a few minutes ago, with a humanity that "remembers" an illusory past.[34]

The link he constructs between Russell and Gosse to examine memory (and the possibility that this may be "false") seems to anticipate in some sense the above-mentioned empirical studies into this issue by neuroscientific researchers.

4. John Stuart Mill (1806-1873)

John Stuart Mill was a British philosopher, economist, and politician, a proponent of utilitarianism and one of Bertrand Russell's mentors. In *A system of logic* (1884),[35] Mill proposes a theory of "semantic categories," which seems to have been particularly interesting to Borges, who revisits it numerous times in his work: in "Tlön, Uqbar, Orbis Tertius,"[36] "Funes, his memory,"[25] "Palabrería para versos" ("Prattle for verses"),[37] and in "John Wilkins' analytical language."[38] The neural correlates of these categories were discovered in recent years, and intense study is being conducted into how they are processed by the brain. This question is revisited later in the article.

In addition to works by the four authors highlighted here, it should be noted that Borges read (and annotated) other books on subjects related to neuroscience. Rosato and Álvarez[15] discuss the existence of an annotated copy of Alexander Luria's *The mind of a mnemonist* (first edition, 1967), in which Luria describes a real patient of his, the mnemonist Solomon Shereshevsky, a very similar case to that imagined by Borges in "Funes, his

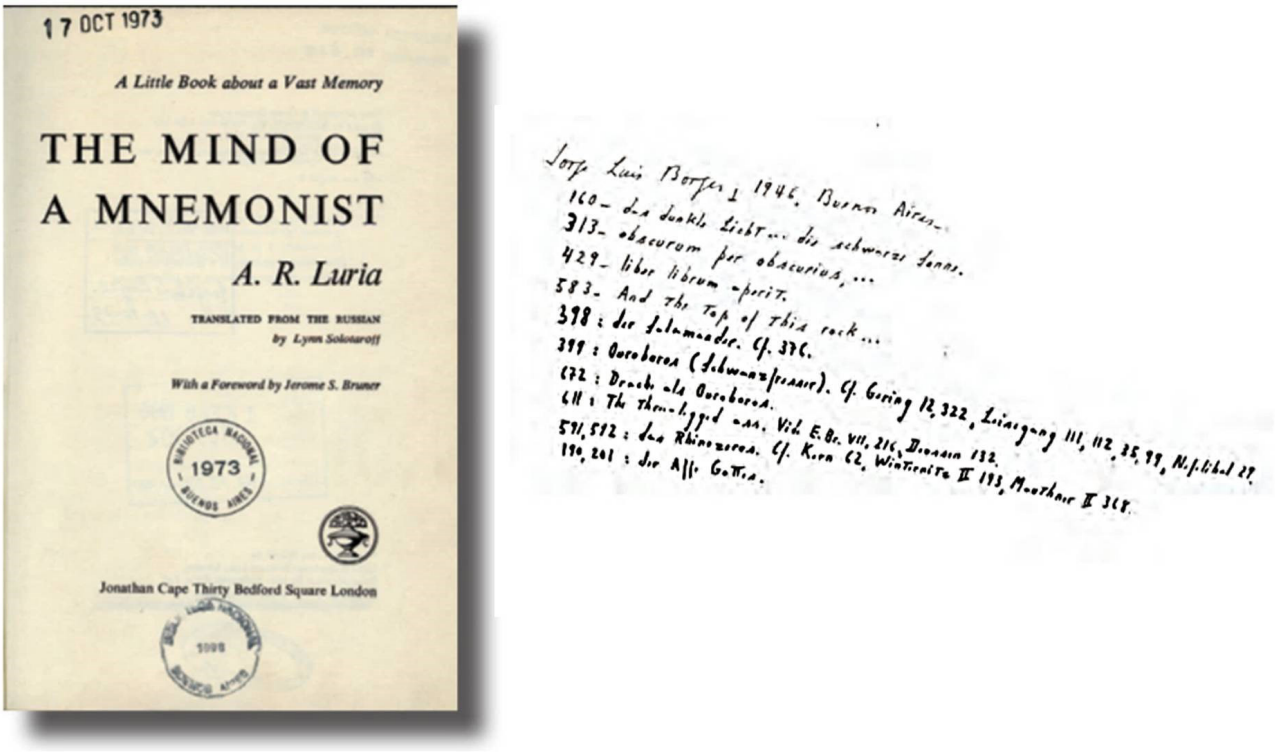

Figure 2. A book by Alexander Luria at the National Library, signed by Borges in 1946, donated to the library in 1973. To the right, Borges' handwritten notes..

memory" (Figure 2). According to the signature in the book (dated 1973), Borges read it long after publishing the short story (1942); thus, we cannot speak here of inspiration but rather of an intriguing coincidence.

Among the texts the author read, we also found such titles as Francis Galton's *Inquiries into human faculty and its development* (annotated in 1928), Henri Bergson's *Matter and memory* (read in 1911), and Robert Burton's *The anatomy of melancholy* (1920 edition, signed in January 1934). In the latter text, Borges notes a suggestive (and brilliantly formulated) idea on the repetitive thoughts of patients with depression: "Melancholy in animals, in plants, in birds, in beasts, in kingdoms" and "Multiplied dogs, unending and ubiquitous."

It is apparent, then, in this synthetic panorama, that Borges read numerous texts on neuroscientific subjects; more importantly, echoes of these texts are apparent in his work. We do not intend to exhaustively discuss each author, but rather to describe a small sample of Borges' creative uses of this reading.

Part II: neuroscientists who read Borges

> *"[...] converges the past—all of our yesterdays, [...] the present and the future."*
> *Conversations* (J.L. Borges and O. Ferrari)[39]

Discussing "Tlön, Uqbar, Orbis Tertius," Ricardo Piglia[40] maintains that in Borges, the question at hand is not how reality enters fiction, but rather the contrary: what is portrayed and explored is the way in which fiction penetrates reality. To extend this hypothesis, we may assert that some of Borges' ideas were realised or discovered by neuroscience years later.

We may cite numerous subjects regarding which the Argentinian writer presents challenges to today's neuroscience: the formation of images during sleep

("Coleridge's dream," "The circular ruins," "The tale of two dreamers"), lucid dreams ("Dreamtigers"), the perception of time in the brain ("The secret miracle"), and the idea of neuronal plasticity related to reading ("My books," in which he writes that "my books [which do not know that I exist] are as much part of me as this face"[41]).

In this article, we will place particular emphasis on three of these dialogues between Borges' oeuvre and neuroscience: neurolinguistics, memory, and spatial orientation.

1. Neurolinguistics

"The crux of my meditation is this: What is the psychological process whereby we understand a sentence?" ("An investigation of the word," *El idioma de los argentinos*[42]). We may affirm that the meditation described by Borges is also the task of many neurolinguists in the present day.[43-49] For instance, researchers in this discipline are studying the perception and generation of concepts and the processing of metaphors.

Regarding the generation and perception of concepts, a key example of Borges' approach to this problem is found in "Tlön, Uqbar, Orbis Tertius." This fantastical story recounts how the narrator (unnamed, but identifiable as "Borges") and his friend Bioy find an (apocryphal) encyclopaedia entry with data on Uqbar, supposedly a region of Tlön, a planet that is unknown but is described in detail, "with its architectures and its playing cards," in a mysterious encyclopaedia ("A first encyclopaedia of Tlön") that the narrator finds among the personal effects of the deceased Herbert Ashe, an old friend of his father's. The volume they found (Vol. XI: *Hlaer to Jangr*) gives detailed descriptions of numerous aspects of Tlön, including psychology and language (this point is further addressed below). In the "postscript – 1947" (already included in the first published version of the story, in 1940), the mystery of Tlön is revealed. In the early 17th century, a secret society of intellectuals called Orbis Tertius was created to invent a country. Two centuries later, the fraternity reappeared in America. A millionaire proposed inventing an imagined planet and suggested that the story be brought together in an encyclopaedia. The publication of the 40 volumes of the "First encyclopaedia of Tlön" was completed in 1914, and the final volume was secretly sent to the society's 300 members, one of whom was Herbert Ashe. In 1944, the encyclopaedia's 40 volumes were found in a library in Memphis, and the discovery was extensively reported by the international press.

A particularly interesting aspect of the story is its description of the language of Tlön, which has no nouns. To name individuals and things, the inhabitants of this imaginary world use impersonal verbs qualified by suffixes and prefixes, or an accumulation of adjectives. Thus:

> There is no noun that corresponds to our word "moon," but there is a verb which in English would be "to moonate" or "to enmoon." […] Nouns are formed by stringing together adjectives. One does not say "moon," one says "aerial-bright above dark-round" or "soft-amberish-celestial" or any other string.[36]

In another text from the same period, "John Wilkins' analytical language"[38] (*La Nación*, 1942), Borges describes how the English linguist (1614-1672) "divided the universe into forty categories or classes, which were then subdivided into differences, and subdivided in turn into species. To each class he assigned a monosyllable of two letters; to each difference, a consonant; to each species, a vowel."[38]

In the same essay he describes an absurd (and apocryphal) Chinese encyclopaedia, the "Heavenly emporium of benevolent knowledge":

> In its distant pages it is written that animals are divided into (a) those that belong to the emperor; (b) embalmed ones; (c) those that are trained; (d) suckling pigs; (e) mermaids; (f) fabulous ones; (g) stray dogs; (h) those that are included in this classification; (i) those that tremble as if they were mad; (j) innumerable ones; (k) those drawn with a very fine camel's-hair brush; (l) etcetera; (m) those that have just broken the flower vase; (n) those that at a distance resemble flies.[38]

In the same text, Borges immediately adds one more of these apparently insane forms of categorising the world:

> The Bibliographical Institute of Brussels also exercises chaos: it has parcelled the universe into 1000 subdivisions, of which number 262 corresponds to the Pope, number 282 to the Roman Catholic Church, number 263 to the Lord's Day, number 268 to Sunday schools, number 298 to Mormonism, and number 294 to Brahmanism, Buddhism, Shintoism, and Taoism. Nor does it disdain the employment of heterogeneous subdivisions, for example, number

> 179: "Cruelty to animals. Protection of animals. Duelling and suicide from a moral point of view. Various vices and defects. Various virtues and qualities."[38]

The neuroscientist Huth and his colleagues at Berkeley, like the institute in Brussels, "exercise chaos," mapping the brain areas that respond to different words, according to their meaning.[45] These researchers observed that semantic information related with people, numbers, or places, for instance, are clustered in specific, distinct areas of the brain, and that the resulting maps show a great resemblance between individuals. In this manner, they identified 100 distinct areas in both hemispheres of the cerebral cortex, forming intricate patterns that are recognisable between individuals, encoding each concept, such as people, numbers, places, foods, tools, or living beings: an authentic "emporium of knowledge." It is perhaps reasonable to enquire about the relationship between the arbitrariness of the classification systems described or imagined by Borges and these mental maps, whose recurrence in different individuals appears to suggest the existence of a "provisional" scheme, which if not divine is at least human.[38]

2. Memory

As mentioned above, one idea that Borges proposed over 50 years ago, born purely of his imagination and without conducting neuroscientific experiments, was that to think is to abstract, and that forgetting is a necessary condition to remembering (as was also proposed by William James). The importance of forgetting in remembering takes a central role in "Funes, his memory," but also in a more elegant and synthetic sense in "A reader":

> (...)
> Having known Latin and forgotten it
> remains a possession; forgetting
> is memory's dim cellar, one of its forms,
> the other secret face of the coin.[26]

The brain's ability to recollect, to connect, and to create mosaics based on impressions lasting milliseconds is the basis of each individual memory.[20] By extension, it forms the basis of our identities, of the self. Once more, Borges offers a beautiful, precise formulation of this in "Cambridge": "We are our memory, we are this chimerical museum of shifting forms, this heap of broken mirrors."[50(p23)]

As mentioned above, each sensory experience causes molecular changes in neurons, configuring the way in which these cells connect with one another. As a result, the brain undergoes constant remodelling based on memory. This plasticity is characteristic of the neurons involved in memory. Therefore, memory is the system itself. The mind makes, transforms, represses, extinguishes, or forgets memories. In this sense, the author is correct when he argues that: "A man's memory is not a summation; it is a chaos of vague possibilities."[51]

Towards the end of his life, Borges published a noteworthy story about how personality is forged by memory: "Shakespeare's memory." In a pub, a character named Daniel Thorpe offers Shakespeare's memory to the protagonist, Hermann Soergel.

> Shakespeare's memory, from his youngest boyhood days to early April, 1616—I offer it to you. […] The story can be told very briefly. It begins in the East, in a field hospital, at dawn. The exact date is not important. An enlisted man named Adam Clay, who had been shot twice, offered me the precious memory almost literally with his last breath. Pain and fever, as you know, make us creative; I accepted his offer without crediting it—and besides, after a battle, nothing seems so very strange. He barely had time to explain the singular conditions of the gift: The one who possesses it must offer it aloud, and the one who is to receive it must accept it the same way. The man who gives it loses it forever.[51]

From that moment, Soergel begins to recognise passages of the Elizabethan writer's life with the clarity of one who had lived it. His own personal memory begins to fade and is gradually replaced by that of Shakespeare.

> What I possess […] are still *two* memories—my own personal memory and the memory of that Shakespeare that I partially am. Or rather, two memories possess *me*. There is a place where they merge, somehow. There is a woman's face ... I am not sure what century it belongs to […] Throughout the first stage of this adventure I felt the joy of being Shakespeare; throughout the last, terror and oppression. At first the waters of the two memories did not mix; in time, the great torrent of Shakespeare threatened to flood my own modest stream—and very nearly did so. I noted with some nervousness that I was gradually forgetting the language of my parents. Since personal identity is based on memory, I feared for my sanity. My friends would visit me; I was astonished that

> they could not see that I was in hell. I began not to understand the everyday world around me (*die alltägliche Umwelt*). One morning I became lost in a welter of great shapes forged in iron, wood, and glass. Shrieks and deafening noises assailed and confused me. It took me some time (it seemed an infinity) to recognise the engines and cars of the Bremen railway station.[51]

What seems to be altered in Soergel are autobiographical memories, the recollection of first-person experience of past episodes referring to spatially and temporally specific life events, rather than semantic knowledge about the world.[52,53] Memories of these individual events occurring over an individual's life guide self-construction and personal identity,[54] and represent a link between what a person has been in the past, what they are in the present, and what they hope to be in the future.[55] Strictly related with the life story of a single person, these memories are also related to personality traits.[56,57] Thus, it seems reasonable that, having substituted one autobiographical memory for another, the protagonist should cease to be who he was before. In this example, Borges uses a fantastical plot to pose a question of great relevance to scientific research: to what extent is identity constituted by memory? Is identity lost when memory is lost? These questions resonate in the story, one of Borges' literary testaments.

In 1942, Borges published in *La Nación* one of his most famous short stories, "Funes, his memory." In it, he tells the story of a Uruguayan farmhand who, after an accident, acquires the incredible capacity to remember absolutely everything, down to the smallest detail. However, this "superpower" made him unable to form general concepts, to the point that "it irritated him that the 'dog' of three-fourteen in the afternoon, seen in profile, should be indicated by the same noun as the dog of three-fifteen, seen frontally."[25]

His infinite memory even became an obstacle to the performance of other tasks: "Two or three times he had reconstructed an entire day; he had never once erred or faltered, but each reconstruction had itself taken an entire day."[25] After meeting him and spending a long night in conversation with him, the narrator reaches a conclusion that, at first glance, appears surprising, but reasonable: "I suspect, nevertheless, that [Funes] was not very good at thinking. To think is to ignore (or forget) differences, to generalise, to abstract."[25]

The lesson of Funes, then, is the importance of being able to forget. Above all, to enable the formation of new memories. In order not to experience the hell of remembering everything, most of which we do not want or serves no purpose. Rodrigo Quian Quiroga, an Argentinian physicist and mathematician who works in the field of neuroscience in England (and who happens to be a great fan of Borges), discovered in 2005 a type of hippocampal neuron capable of generating abstract representations of concepts.[58] Experiments using microelectrodes to record the activity of these cells found that the same group of three or four neurons presented selective, invariable, multimodal activation in response to a particular concept. The neurons fired when the patient was presented with different images, or the spoken or written name of, for instance, Jennifer Aniston (hence these "concept" neurons being referred to as "Jennifer Aniston neurons").[58,59] In her doctoral research, the young Argentinian biologist Belén Gori aimed to replicate the same experiments, recording the activity of individual neurons with popular figures, leading to the identification of "Diego Maradona neurons," for example.[60] These neurons may constitute a link between perception and memory, creating the abstract codification that we use to store memories.[4,58] Their absence may limit the capacity to generate abstractions, as observed in Funes.

3. Spatial orientation

"The universe (which others call the Library) is composed of an indefinite, perhaps infinite number of hexagonal galleries."[61] These are the opening lines of "The library of Babel," a story published for the first time in *The garden of forking paths* (1941) and later in *Fictions* (1944). The story describes a library containing all possible books, both existing texts and those yet to be written. The library has existed for all eternity, since before mankind. Thus, both the library and the librarians may be a work of God or a product of chance. Its architecture is richly described, with mathematical details, which enabled the architects Kate and Andrew Bernheimer[62] to draw plans of it in 2013.

The rooms of the library, called hexagons, are illuminated by glowing fruits. The library's numerous visitors (euphoric, dogmatic, and anguished characters) strangle one another in its corridors. The narrator presents a diverse gallery of characters, described with features that recall religious history: pilgrims combing the shelves

for a holy text, inquisitors seeking to destroy what they view as blasphemy, mystics who hope to find the book that will reveal the meaning of the universe, heretics of various types, etc.

The imaginary architecture that Borges describes in the library is (coincidentally?) the same as that used by the grid cells of the temporal lobe, which orient us in space, dividing it into hexagons, as discovered by Britt and Moser in research that won the Nobel Prize in 2014.[63,64] The firing of these neurons divides space into a grid of hexagonal cells (made up of triangles), which Borges refers to as the "necessary shape":

> Idealists argue that the hexagonal rooms are the *necessary shape* of absolute space, or at least of our perception of space"[61] [emphasis added].

The hexagon is probably the most commonly used ornamental form in history, and in natural structures (beehives, etc). This is echoed in the idea of Benard cells in fluid dynamics[65]: when a liquid is heated from the base, the effect of Archimedes buoyancy or of a variation in liquid-air surface tension, or a combination of both mechanisms, causes the system to pass from a chaotic situation to a self-organised structure of hexagonal cells. The Library of Babel is also a self-organised system. These patterns, which form spontaneously through self-organisation arising from what Borges calls "divine disorder," suggestively recall the patterns formed in the books of the Library, which are "often illegible, but never without meaning."[61]

In "Death and the compass" (1942),[9] the geometric configuration of space is interwoven with the development of the story. It is a metaphysical detective story about a series of murders committed in a city. The first victim is Dr Marcel Yarmolinsky, a Jewish scholar who arrived in the unnamed city to attend a Talmudic congress. The investigators responsible for the case, police commissioner Trevinarius and amateur detective Erik Lönnrot, reach different conclusions. The former imagines a bungled burglary, while Lönnrot prefers an explanation linked to Jewish mysticism, due to the discovery of an incomplete text among the belongings of the deceased rabbi that includes the phrase "The first letter of the Name has been written." The detective argues that "What we have is a dead rabbi; I would prefer a purely rabbinical explanation." Further murders are committed, each on the third day of three consecutive months (December, January, February) at different cardinal points. The murderer left written phrases relating each crime to the rabbi's text. After the third crime, the police received an anonymous letter arguing that there would not be a fourth murder as the locations of the previous three formed a perfect equilateral triangle.

This detective story may be interpreted as a parable about how the brain generates the experience of space. Grid cells are often likened to a GPS or inner compass enabling us to navigate without getting lost. The murders in the story take place at particular points in space that form a geometric figure, in the same way that the brain organises the perception of space. The creation of a grid in the brain provides a sense of distance, based on movement and the knowledge of previous positions. Moser's "triangular matrix tiling the entire environment available to the animal" is reminiscent of the "mystical, equilateral triangle" described in the story.[9] As a corollary to this question, we may consider that if this grid is needed to orient ourselves, we may get lost travelling on a straight line. At the end of the story, facing imminent death, the protagonist describes it as follows: "I know of a Greek labyrinth that is but one straight line. So many philosophers have been lost upon that line that a mere detective might be pardoned if he became lost as well."[9]

Conclusions

Of course, any of the lines drawn in this article may be further developed (and other researchers have already made progress in this direction, as shown by the works cited throughout the article). Borges' work is multifaceted and, for this reason, boundless. He seems to have wanted to encompass the infinite, unfolding his work in numerous directions and spanning diverse genres, in dialogue with all types of knowledge.

The aim of this brief review is, on the one hand, to document Borges' interest in problems studied today by neuroscientists, demonstrated by his readings and by the subjects addressed in many of his texts. Secondly, we aimed to show how Borges' fiction invites us to reflect on the nature of many current subjects in neuroscientific research. Without knowing it, the writer was a precursor to many contemporary scientific discoveries, demonstrating how, rather than being in conflict, the humanities and the sciences are travelling the same paths.

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Conflicts of interest

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