



THE GARDEN OF THE FORKING WORLDS

Borges and Quantum Mechanics

by Alberto G. Rojo

Entrance to the labyrinth

On July 9, 1985, by happenstance, I exchanged a few words with Jorge Luis Borges. It was the morning after my wedding and before taking off to our honeymoon, my wife and I went to greet my parents who had come from Tucumán to Buenos Aires, and were staying at the Hotel Dorá, on Maipú Street. My mother grabbed me by my arm and took me to the dining room. All the tables were empty, except for one, and there was Borges, having lunch with a woman who perhaps was Estela Canto, and with whom he spoke alternating Spanish with English. I was paralyzed with fascination and examined him just as we look at statues that have no sight. He was dressed in a dark suit, a neat tie, and his plate had an austere portion of white rice. My father persuaded me to approach him, so we waited until he finished his lunch, and when the waiter, who addressed him as “maestro”, brought him a cup of tea, we walked to his table. My father started the conversation and Borges, who was thrilled with the idea of chatting, treated us with some erudite fables. He spoke of God, the minotaur, and crit-

icized harshly Ortega y Gasset (“I met him during his visit to Argentina and he impressed me as zero”).

My only intervention was to tell him that some physics texts made reference to his work. At that time I was an undergraduate student at the Instituto Balseiro in Bariloche, and I was alluding to references to “The Lottery in Babylon”, where Borges reflects on randomness and determinism. Borges expressed his ignorance in matters of physics with a disconcerting answer that I was to repeat innumerable times. A personal anecdote with Borges is a wonderful opportunity for vanity. Everybody knows that his fame is a universe in constant expansion but a few realize that he is a very accessible man who would be equally pleased to talk to the notable as to the unknown.

I later came across numerous citations to Borges’ work in scientific texts and popular science writings: references to “The Library of Babel” to illustrate the paradoxes of infinite sets [1] and fractal geometry [2]; mentions to the fantastic taxonomy of Doctor Franz Kuhn in “The Analytic Language of John Wilkins” [3] (a favorite among neuroscientists and linguists); comments on to “Funes, His Memory” regarding the present numbering systems [4]; and, recently I was surprised to find a quote from “The Book of Sand” in a paper about segregation of granular mixtures [5].

All these, however, are just metaphorical examples meant to color the grayness of technical explanations. A notable exception is “The Garden of the Forking Paths”, where Borges proposes, unknowingly (there is no way he could have known), a solution to a still unsolved problem in quantum mechanics. “The Garden . . .”, published in 1941, anticipates literally Hugh Everett III’s doctoral thesis, published in 1957 under the title “Relative State Formulation of Quantum Mechanics”[6] and that Bryce DeWitt later popularized as the Many Worlds Interpretation of Quantum Mechanics. The curious correspondence between a physics paper and a short story is the subject of the present article.

Quantum Paths

The laws of quantum mechanics describe the behavior of the microscopic world; a world in which objects are so light that the pressure of a light ray, however dim, can cause abrupt displacements. Those objects—atoms and molecules invisible to the human eye—move and interact among themselves in a way qualitatively different from tennis balls, automobiles, airplanes, and the rest of the fauna of the visible world. Let us see how.

In both descriptions of the world, microscopic and macroscopic, it is useful to talk about the state of an object. A possible state of a tennis ball is: at rest beside the net. Another possible state is: one meter above the ground moving upwards at a velocity of one meter per second. In this language, to specify the state of a tennis ball at a given moment is to indicate its position and velocity at that moment. The laws of classical mechanics, enunciated by Isaac Newton, allow us to predict, given the state of a tennis ball at an initial moment, the state of the ball at every later time, and the sequence of states in nothing but the trajectory of the tennis ball. The microscopic world, ruled by quantum mechanics, does not work this way. Atoms and other microscopic particles do not admit a description in which indicating the state of a particle at a given time corresponds to indicating both the velocity and the position. In quantum mechanics, to specify the state of the particle at a given time is to provide a certain function that contains the probability that the particle is at a certain place with a certain velocity. The laws of quantum mechanics, formulated by Erwin Schrödinger and Werner Heisenberg, allow us to calculate the temporal changes of that probability function (or, in more technical terms, the wave function). The changes in state are not changes in the position of the particle but changes in the wave function. This is the first conceptual revolution of quantum mechanics: the loss of the idea of a trajec-

tory in favor of a description in terms of probabilities of trajectories.

But the story does not end here; after all, often our every day world faces us with situations in which randomness plays a crucial role and which require a description in a probabilistic language. In order to compare two probabilistic visions, classical and quantum, let us consider the simplest of the random experiments of the macroscopic world: Alice flips a coin and holds it in her closed hand. Mary has to predict if the coin in Alice's hand fell heads or tails. From Mary's point of view, the state of the coin (let's forget for a moment it's velocity) could be described by a (classical) probability function that assigns to each state, head or tail, a fifty per cent probability. Although Mary would have to wait until Alice opens her hand to find out if the coin fell heads or tails, it is "obvious" that the coin fell in one and only one of the two possibilities, and that the probabilistic description in this case only quantifies Mary's ignorance about the state, or the position, of the coin. When Alice opens her hand, Mary verifies that the coin fell, let us say, heads. We could also talk about the change of state of Mary's memory, which went from ignoring how the coin fell to knowing that it fell heads. The state of the coin, however, did not change: the coin had fallen heads and the observation revealed a result that existed beforehand.

Let us compare this experiment with its microscopic counterpart. Even though quantum coins do not exist, there are systems (atoms) that can be in one of two mutually exclusive states. The expert reader will realize that I am talking about the spin of an atom, that can have either of two values, up or down. Let us say we have an atom in a closed "box" (playing the role of Alice's hand) and that we know that the atom's wave function corresponds to fifty per cent up and fifty per cent down. In analogy with Alice's coin, if we open the box we will see the atom in one of the two possibilities and if we repeat the experiment many times preparing the atom in the same initial state, we will verify that approximately half of

the times the spin is up and almost half of the times it is down. Up to here the two probabilistic visions coincide.

However, quantum mechanics admits the possibility that the atom be in a superposition of states before it is observed and in a well defined state after it is observed. Let us say that Mary has now a detector capable of opening the box and observing the spin of the atom. After the measurement not only Mary's memory changes but so does the state of the atom. The crucial difference is in the fact that before the observation the atom is in a superposition of two states and it does not make any sense to say that it is up or down. It is simultaneously in both.

This constitutes the second conceptual revolution of quantum mechanics: the loss of the idea of an objective reality. To Niels Bohr, whose vision we know as the Copenhagen interpretation and which represents the dominant orthodoxy, the microscopic entities differ from the macroscopic ones in its ontological status and the philosophical problem stops there. In other words, it only makes sense to speak of the state of a microscopic particle once it has interacted with a (macroscopic) measuring device. But then the difficulty is aggravated because quantum mechanics claims to be a unified and complete description of the world; and, if it contains alarming elements that challenge our intuition at a microscopic level, there is no way to prevent these effects from propagating their infections into the macroscopic world.

The central question that summarizes the still unresolved measurement problem, can be formulated in the context of our example as follows. If both Mary and the atom are subject to quantum laws, and if the atom is in a superposition of states before the measurement and in a well defined state after the measurement. What is the mechanism through which the atom "chooses" one state and not the other? The generalized consensus is that the solution to this dilemma exceeds the limits of quantum mechanics, that solution lies beyond the quantum theory, which notwithstanding has the greatest power of prediction and explanation of virtually any physical theory.

The only “solution” to the paradox could lie in Everett’s theory, which even though it proposes a coherent way out, is too bizarre for the taste of some physicists, who accuse it of being “verbal placebo” [7], “extravagant” [8], and of “carrying too much metaphysical luggage”[9]. We arrive at the central crossing in the labyrinth: we either accept that quantum mechanics is incomplete or accept the contested theory of the parallel worlds of Everett and DeWitt, in which case the world would be precisely the labyrinth conceived by Ts’ui Pên, who

“. . . believed in an infinite series of times, a growing, dizzying web of divergent, convergent, and parallel times. That fabric of times that approach one another, fork, are snipped of, or are simply unknown for centuries, contains all possibilities. In most of those times we do not exist; in some, you exist but I do not; in others I do and you do not; in others still, we both do.”[10]

Ts’ui Pên’s bifurcations and Hugh Everett III’s ramifications

In the forward to the original edition of *Ficciones*, his first collection of short stories, Borges announces that “The garden . . .” is a detective story. The spy Yu Tsun, the story’s protagonist, is a spy working for the Germans during World War I, and must send them the name of a town. Followed by the implacable captain Richard Madden, he decides to communicate the message by killing the renowned sinologist Stephen Albert, whose last name is that of the French town the British are about to attack. He knows that he would be executed right after murdering Albert, and that when the British newspapers publish both names, the Germans would get the message. Yu Tsun finds Albert’s address in the phone book and, once there, by a fortuitous Borgesean coincidence, Albert recognizes Yu Tsun as the great grandson of the Chinese astrologist Ts’ui Pên, who has written an extraordinary book: *The Garden of Forking Paths*.

Ts'ui Pên had once set for himself an extraordinary task: to build an infinitely complex labyrinth and to write an interminable novel. After his death everyone considered that he had failed because the labyrinth's existence was unclear and the novel was not only incomplete but the result absurd and incoherent (for example, some characters would die and reappear in later chapters.) To Yu Tsun's surprise, Albert reveals his discovery about the enigmatic novel: the book is the labyrinth and the labyrinth is not spatial but temporal. The Garden is the image of the universe as conceived by Ts'ui Pên, and, if we accept Everett's hypothesis, the world is a garden of forking paths.

Let us come back to the experiment of Mary and the atom. According to the many worlds theory, right after Mary becomes conscious that the atom is in a well defined state, the universe divides itself in two almost identical copies, in one the spin is pointing up, in the other it is pointing down. In each quantum measurement the universe ramifies with one component for each possible result of the experiment. In one universe, Mary's memory corresponds with the spin pointing up; in the other with the spin pointing down. The sequence of configurations of Mary's memory, or the "trajectory" of her memories is different in each universe.

Both authors present the central idea in remarkably similar ways. In section five of his original article Everett says:

"The 'trajectory' of the memory configuration of an observer performing a sequence of measurements is thus not a linear sequence of memory configurations but a branching tree, with all possible outcomes existing simultaneously." [6]

In "The Garden . . .", Borges says:

"In all fictions, each time a man meets diverse alternatives, he chooses one and eliminates the others; in the work of the virtually inextricable Ts'ui Pên, the character chooses—simultaneously—all of them. He creates,

thereby, 'several futures', several times, which themselves proliferate and fork." [11]

Where are all these universes? One answer is that they are "here", where "our" universe is. According to the theory these universes don't interact and there is no reason to exclude the possibility that they are occupying the same space. Another answer is that they are "piled up" in an additional dimension of which we know nothing. This possibility should be distinguished from the "infinite dimensions of time" mentioned by Borges in his essay about J. W. Dunne in *Other Inquisitions*. According to Dunne, whose writings perhaps inspired Borges, those dimensions are spatial and he even talks about times perpendicular to each other [12]. This "geometrization" of time does not fit in the many worlds theory and is certainly different from Ts'ui P'en's ramified time.

Borges seems to be the first to formulate this alternative to linear time. The other possibility, that of a cyclic time has numerous precedents in ancient cultures [13] and in literatures alluded by Borges in many of his writings. With multiple times the story is different: "Hume denied the existence of absolute space in which each thing takes place; I deny that of a single time in which events are linked. To deny coexistence is not less arduous than to deny the succession" [14].

While I was compiling the material for this article I asked Bryce DeWitt, then at the University of Texas at Austin, if he knew about Borges's story in 1971 when he coined the term "many worlds". He told me he did not, and that he found out about the short story through the British physicist Lane Hughston from Oxford. In a compilation of articles published in 1972 where an enlarged version of Everett's original paper is included, an epigraph cites "The Garden . . ."[15].

Finally, what does this astonishing parallelism teaches us? After all, coincidences exist and sometimes induce us to confuse correlation with cause and effect and similitude with representation [16]. In my opinion, the similarity between the two texts show us the extraordinary way Borges' mind was im-

mersed in the cultural matrix of the twentieth century, in that complex web whose secret components ramify beyond the demarcations between disciplines. The structure of reasoned fiction of Borges' short stories, that sometimes resemble theorems with fantastic hypotheses, is capable of distilling ideas in embryonic form that before becoming theories make a temporary stop in literature. While Everett's and DeWitt's ideas can be read as science fiction, in "The Garden . . .", fiction can be read as science.

In that July morning I was disconcerted by Borges's answer; today I understand it as a revealing metaphor of what we can know without knowing we know. I remember he said:

"How strange! This is really curious because the only thing I know about Physics comes from my father, who once showed me how a barometer works."

He said it with an oriental modesty, moving his hands as though trying to draw the apparatus in the air. And then he added:

"Physicists are so imaginative!"

REFERENCES

[1] See for example R. Rucker, *Infinity and the mind* (Boston: Birkhäuser, 1982).

[2] F. Merrell, *Unthinking Thinking*, Jorge Luis Borges, Mathematics, and the New Physics (West Lafayette: Purdue University Press 1991).

[3] S. Pinker, *How the Mind Works* (New York. W. W. Norton, 1997).

[4] Philip Morrison, "The Physics of Binary Numbers", *Scientific American*, February de 1996, p. 130.

[5] H. A. Makse et al., "Dynamics of granular stratification" *Physical Review E*. Vol. 58 (1998). p. 3357.

[6] H. Everett III, *Reviews of Modern Physics* Vol. 29 (1957). p. 454.

[7] A. J. Leggett, “The Problems of Physics” (Oxford: Oxford University Press, 1987) p. 172.

[8] J. S. Bell. “Speakable and unspeakable in quantum mechanics”. (Cambridge: Cambridge University Press, 1987) p. 133.

[9] See for example A. Rae, “Quantum physics, illusion or reality?” (Cambridge: Cambridge University Press 1986) Chapter 5.

[10] J. L. Borges. *Collected Fictions*, translated by Andrew Hurley. (New York: Viking, 1998). p. 127.

[11] Ref. [10], p. 125.

[12] J. W. Dunne, “An experiment with time” (New York: The MacMillan Company, 1949).

[13] B. C. Sproul, “Sacred Time”, in *The Encyclopedia of Religion*. Mircea Eliade, ed. (New York: MacMillan, 1987). See also M. Eliade, “Cosmos and History: The Myth of the Eternal Return”, trans. W. Trask, (Princeton, NJ: Princeton University Press, 1959).

[14] J. L. Borges, “Nueva Refutación del tiempo”, in *Otras Inquisiciones* (Buenos Aires: Sur, 1952) p. 202.

[15] B. S. DeWitt y N. Graham, “The Many-Worlds Interpretation of Quantum Mechanics” (New Jersey: Princeton University Press, 1973).

[16] F. Capra in his book “The Tao of Physics” (Boulder: Shambhala, 1975) falls in this trap by drawing conclusions about “parallels” between ancient mysticisms and modern physics.