Fully Non-Local Optimization as Origin of Quantum Randomness

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Abstract

An elemental scheme for an alternative theory to quantum mechanics is proposed. The aim is to reproduce quantum phenomenology avoiding intrinsic randomness and action at a distance, but allowing temporal and spatial non-locality.

The hypothesis is that all particle dynamics are driven by a non-local but real optimization principle which determines trajectories by minimizing/maximizing a quantity. This quantity is computed uniformly over an unbounded cluster of events no matter when or where they take place. These events are understood as the points where a possible path forks and each option contributes differently to the optimized quantity.

In this article the mechanism is sketched using a toy model for the measurement of a particle of spin 1/2 (or two for the entangled case) where the events computed for the particle path are kept discrete and dual. The calculation that follows is aimed to provide a natural yet non-local explanation of the violation of Bell inequalities without the requirement of any intrinsic randomness or express ‘hidden variables’. No method or formalism from current quantum mechanics is intended to be used. Only the experimental outcomes for measurements of spin 1/2 particles are considered.

1 Introduction

From the beginning of quantum theory, its intrinsic uncertainty and randomness has produced a widespread intellectual discomfort that can be coined by Einstein's quote 'God Does Not Play Dice with Universe' [EPR35]. Naively introducing local hidden variables, not only have already been ruled out by the confirmation of the violation of Bell inequalities [Bel64], but also imply adding a gratuitous extra parameter to determine each measurement outcome. However, the attempts of finding out wether or not that behaviour is fundamental to nature still make sense.

Even when neither locality nor realism is free of being questioned, I believe that is much more philosophically promising to give up on locality than on realism, since it implies no absolute resignation from our chances of pushing the limits of knowledge. The task which would be left is to understand how non-locality flows in the physical reality producing random results for apparently perfectly symmetrical and minimal experimental schemes. Before accepting intrinsic non-realism, the logical attempt is to search for dynamical principles that embrace all what is around any experiment far away from what has been already considered and include adjacent phenomena in the computation.

Besides that, we also count with a very strong old theory which has always worked extensively and that it might not have been taken seriously enough: the least action principle. The problem might be -and have always been-, not the principle itself, but the way of finding out the quantity to optimize and calculating it.

The principle of least action is transformed by Quantum Mechanics into the Feynman Path Integral Formulation[Fey65] where the action contributes to the probability of the particle going a certain path, but no longer rules it. Nonetheless in the end, a path is taken or not, besides probability, so that idea is likely to be ultimately unsatisfying and it could be very well the other way around: action determines the only path for the particle and Feynman theory works because it would evaluate the chances of the local action to dominate the full action.

2 Purpose and motivation

This proposal is motivated by a feeling of unease with the current theory of quantum mechanics and pursues finding theoretical, technical and mathematical support to establish potential foundations and carry out calculations. I also expect to get to know people seeking similar approaches. As a warning I must say that the theory implies some form of retrocasuality and superdeterminism, but in such an essentially non-computable way that it can still leave some room for free-will issues in a philosophically appealing fashion. I expose the ideological thread which led me to this idea in 'Quantum and a Half' (This is a fictional work that can be found here: qaah.xyz). So far, it is mostly written in spanish.

3 Scheme of the theory

3.1 General theory: How particles choose their paths

The assumption is that the path of every particle in the universe is chosen so that a determinate quantity S, envisaged as an abstract action, must be a minimum. In principle, S should be minimal for all universe as a single system. This quantity is computed for each possible history of the universe, from the hypothetical beginning of the universe to the end of times, both of them assumed to be infinitely far away from the measured event analyzed, located at present. For every situation where one or more particles can take different possible paths, each possible choice sums up a certain value to the total S of the path. At all times, before, after and in-between any of these path changing events (equivalent to wavefunction collapses in quantum mechanics), the position, momentum and spin orientation for all particles is ALWAYS well-defined (even if not accesible by the experimenter). There are no superpositions in the theory. Nonetheless, the information about the particle's choice is not in 'hidden variables', it is in the rest of the events of its lifespan, which contribute to the total S as much as any other. From all the possible paths for the full life of the universe only one is chosen, the one with the minimum/maximum score for S compared to the rest of the paths.

3.2 Theory reduced to binary spin choices

Since at first glance the idea of the theory seems unfeasible, my first step is to get rid of the ideas of space-time, energies and dimensional quantities so that the paths of particles are reduced to spin choices made at ideally point like events. This is: a particle, during its lifetime, goes through different states of spin + and - (I will call the possible spin values + and - because $\frac{1}{2}$ means nothing here and is simpler than $+\frac{1}{2}$ and $-\frac{1}{2}$)along a direction, envisaged at first in an abstract way.

3.3 Toy model with one or two particles and ethereal beam splitters

As chasing many particles mutually interacting in all possible ways can be hard to do, for the toy model scheme I propose, I will consider a 'universe' plagued with 'ethereal' measuring devices. 'Ethereal' in the sense they can not contribute to the sum of S. They are only there to give the 'non-ethereal' particles the chance to take a path bifurcation weighted with different 'scores' for the quantity S and enabling us to track a single path and not many. Of course, in a full theory real devices would be made of particles and particles would interact with particles. But this artifice is just to make the idea manageable.

The toy model consists, in principle, of a single particle whose spin has been measured and is therefore KNOWN. This particle is first measured by a -ethereal- polarizer device whose orientation regarding the particle spin is KNOWN (our device). After that, the particle will undergo (as so has before) indefinitely many measurements processes passing through polarizers whose orientation is NOT KNOWN. The reason for this is that, for any experiment, one has control and get a measurement result for a point-like choice of nature, not for a full path. The rest of the events before and after the one we are measuring are out of our control so we should consider them, in principle, evenly distributed: they should be described by an uniform probability distribution.

The second step is a toy model to reproduce the situation explored by Bell Inequalities. It should mimic two entangled spin 1/2 particles in a singlet state but that, in this theory, would be given by two particles with well-defined spin vectors but total spin 0. Although no total spin can be observed, there is a direction the set is pointing to and it is determined by the optimization principle itself. Therefore, the set-up for the 'entangled' pair consists of two particles with the constraint of both spins to be pointing in opposite directions. These particles are then, in a similar way, measured first by two polarizer devices (Alice and Bob) with a KNOWN orientation between them (the angle agreed by Alice and Bob). Unlike for the single-particle case, the orientation of each of the two particles respect the devices is NOT KNOWN by the experimenter, nor is the angle of interaction with the rest of the two infinite series of measuring devices which affect the particles' lives after Alice and Bob have measuring them.

3.4 On angles as abstract entities

The scheme posed here is based in 'angles' but do not require geometrical considerations about angles in space or time. In fact, it is something that I expect to be emergent from the structure of the theory, alike the case of Spin Networks[Pen71]. For my purposes it makes more sense to define an 'angle' as a continuous 'degree of agreement' between two binary states, + and -, so that 1 is full agreement (with +) and 0 is full disagreement (or agreement with -). Therefore I redefine traditional angles, Θ,so that $\pi \to 0$ and $0 \to 1$ in the following way: $\Theta \to \theta = 1 - \Theta/\Pi$ Or for better operation I shall use

$$\theta(\Theta) = 1 - 2\left|\frac{\Theta}{\pi} - \left\lfloor \frac{\Theta}{\pi} + \frac{1}{2} \right\rfloor\right| \tag{1}$$

which is just inserting everyday angles in a triangular wave function to get them back in the [0, 1] interval. This transformation may seem unimportant (and it is), but it conceptually releases the idea of 'angle' from geometry and euclidean space: The angle between two spins is just a 'degree of agreement'. The reason to do this is that in this theory as proposed here only relative angles are considered as drivers of the dynamics and, for the calculation of the quantity S, any function of this 'abstract angles' could do the job. I mean: There is no strong reason to assume a way in which angle measurements should contribute to the quantity S. The meaning of this is that the factor ω_i depends on the angle θ_i (which is the angle between the spin of the particle and the detector found after $i-1$ interactions) but it could do so as any function of the angle, $f(\theta)$, for + direction option, and its opposite $1 - f(\theta)$, in such a way that values between 0 and 1 are alway returned. I could someone legally choose any function f, so that it comply with experimental results. But that would not feel right at all. However, it is philosophically natural for me to start by simply and naively considering just the angle, this is f to be the identity, $f(\theta) = \theta$, just because the only 'identity' implied is 'angle' -whatever it may be- and it makes no sense distorting it in any way. Therefore I will assume:

$$f(\theta) = \theta \implies \omega_{i+} = f(\theta_i) = \theta_i \text{ and } \omega_{i-} = 1 - f(\theta_i) = 1 - \theta_i \tag{2}$$

for the rest of the developement, but keeping in mind that making the substitution $\theta_i \to f(\theta_i)$ could be reconsidered.

4 Results

4.1 Outcome for thought experiment with one particle

Consider a particle heading towards a detector-polarizer. We know the spin orientation, the angle, of the particle respect to that detector. The detector will measure the particle, giving + or - as result, and force its spin to the orientation of the detector, with + or - sense. Depending on the choice of + or - and the relative angle, this measuring event will contribute to S with a different amount. After this interaction the particles goes on finding many other similar events but they are different depending on each choice. Since we can only know the angle of our detector, let us assume that all the angles that we do not know can take any value in an equiprobable way.

Let us go over it: The particle starts at time 0, there is no past. The first thing it will do is to interact with a measuring device with a KNOWN angle. After that, depending on whether the measurement is + or -, it will continue interacting with more and more measuring devices. Every time the particle interacts with a device it must take the direction of that detector-polarizer, with a choice for the sense: + or -. According to the chosen direction, its previous score (say it is 1 initially) is multiplied by a factor between 0 and 1 according to its θ angle with respect to the detector: 'θ/π' for the + direction and '$1 - \theta/\pi$' for the $-$ direction.

Since there is a factor for every detector on the path, all the factors together compose an infinite product which could be written as minimazing a cumulative 'action' as follows:

$$\omega_1 \cdot \omega_2 \cdot \omega_3 ... = e^{-S_1} \cdot e^{-S_2} \cdot e^{-S_3} = e^{-S_1 - S_2 - S_3} = e^{-S} \tag{3}$$

I prefer to use factors in a product which is kept between 0 and 1 for the resemblance with probability (but they mean not probability). But it can be expressed equivalently as the maximization of the 'score' e^{-S} or the minimization of S. From the starting point, and after passing through the first detector with angle θ_0, the particle must decide between two different trajectories towards the future through a series of infinite detectors with unknown angle $\theta_n(+)$ or $\theta_n(-)$ for n growing towards the future. We want to evaluate the probability that the particle chooses, depending on θ_0, one option or the other assuming that all the other angles θ_1 to θ_∞, are random and equiprobable. 'When' and 'where' these events happen is unsignificant here since we evaluate choices. This produces a series of events that bifurcate indefinitely like this:

$$\theta_0 \left\{ \begin{array}{l} \theta_{1+} \left\{ \begin{array}{l} \theta_{2++} \left\{ \begin{array}{l} \theta_{3+++} \left\{ \begin{array}{l} \theta_{4++++} \left\{ \begin{array}{l} ... \\ ... \end{array} \right. \\ \theta_{4+++-} \left\{ \begin{array}{l} ... \\ ... \end{array} \right. \end{array} \right. \\ \theta_{3++-} \left\{ \begin{array}{l} ... \\ ... \end{array} \right. \end{array} \right. \\ \theta_{2+-} \left\{ \begin{array}{l} \theta_{3+-+} \left\{ \begin{array}{l} ... \\ ... \end{array} \right. \\ \theta_{3+--} \left\{ \begin{array}{l} ... \\ ... \end{array} \right. \end{array} \right. \end{array} \right. \\ \theta_{1+} \left\{ \begin{array}{l} \theta_{2-+} \left\{ \begin{array}{l} \theta_{3-++} \left\{ \begin{array}{l} ... \\ ... \end{array} \right. \\ \theta_{3-+-} \left\{ \begin{array}{l} ... \\ ... \end{array} \right. \end{array} \right. \\ \theta_{2--} \left\{ \begin{array}{l} ... \\ ... \end{array} \right. \end{array} \right. \end{array} \right. \tag{4}$$

This means, if for θ_0 the particle chooses + (or -), then it will find a new detector where it will have to choose again + or - for the angle θ_{1+} (or θ_{1-}), after this it will have to choose between θ_{2++} and θ_{2+-} if it chose + or, if it chose -, between θ_{2-+} and θ_{2--}. That's already 4 possibilities, then between 8 and then between 16, and so on...

Each possible path P can be encoded by an infinite binary sequence N (the possible paths are uncountable and fork in the way the Cantor Set does), so that the outcome for the measure at each node in the path is given by the '1' or '0' digit at that position in the sequence.

The score $\mathcal{P}$ of a given path P within the set $\{P\}$ of all possible paths will be:

$$\mathcal{P}(N) = \omega_{N(0)}(\theta_0)\omega_{N(1)}(\theta_{r_1})\omega_{N(2)}(\theta_{r_2})...\omega_{N(\infty)}(\theta_{r_\infty}) \tag{5}$$

where:

$$\begin{array}{l} N \to \infty \text{ binary sequence} \\ N(n) \to n^{th} \text{ term of N binary sequence} \\ \theta_r \sim U(0,1) \\ \omega_+(\theta_r) = \omega_1(\theta_r) = \theta_r \\ \omega_-(\theta_r) = \omega_0(\theta_r) = 1 - \theta_r \end{array} \tag{6}$$

The path actually taken by the particle will be: P' such that:

$$S(P') > S(P) \quad \forall P \tag{7}$$

In a concrete case, if, ideally, we could know all possible angles θ_1 along all possible trajectories, we could predict exactly the outcome of any measurement on the particle. The problem is that this is clearly unfeasible outside of a thought experiment, so we will consider all other angles to be random and equiprobable (this is to say that the Heisenberg uncertainty principle would come from not knowing the future history of the particle. I do not make reasonings about the past because I am already assuming that the particle is passing through detector 0 forming an angle θ_0 and that for whatever reason we know it).

Finding the particle's true path consists of finding the maximum value for e^{-S} from among all the possibilities of products of the factors of each interaction. All interactions choices conform the possible paths branching off at each random angle vertex. The outcome probability for the measurement of our device arranged with angle θ_0 is given by calculating the probability that the optimal path is to the + side (with weight factor θ_0) or to the - side (with weight factor $1 - \theta_0$).

In order to make the handling easier and also make way for possible computer approaches and approximations I can rewrite this using this recursive function:

$$\Omega(n) = \begin{cases} 1 & : n = 0 \\ \max \begin{cases} \Omega(n-1) \cdot \theta_r \\ \Omega'(n-1) \cdot (1-\theta_r) \end{cases} & : n > 0 \end{cases} \tag{8}$$

where θ is a random number between 0 and 1 generated on the fly at every function recall. Note that the function is built to deepen in the future structure of paths n steps so that far future lies at step 0, once this far future is reached the function gets back to present checking to keep the maximum value for any 2 choices. The interesting random variable to operate with is:

$$\Omega(\infty) \equiv \lim_{n\to\infty} \Omega(n). \tag{9}$$

So the problem of calculating the probability that, given a θ_0, the particle chooses + will consist of calculating:

$$\mathbb{P}(\theta_0 \Omega(\infty) > (1-\theta_0)\Omega(\infty)), \tag{10}$$

or, for it to choose -, its complementary.

It is important to note that $\Omega(\infty)$ is an infinitely small quantity ($\lim_{n\to\infty} \Omega(n) = 0$), but it is not fixed but random, so the outcome of two separate runs of the function can be compared: $\Omega(\infty)_a/\Omega(\infty)_b$, this quotient is neither fixed. It follows a probability distribution which depends on an infinite number of uniformly distributed random numbers. Obviously, one would expect the probability distribution for the particle to be measured in the $\pm$ direction with angle θ_0 ultimately ends up going as $\sim \frac{1\pm\cos(\theta_0)}{2}$.

4.2 Outcome for thought experiment with two particles in a singlet state

The previous section exposes the way a measurement of a spin $\frac{1}{2}$ particle by a detector could be modeled. Let us try now to approach the case of two entangled particles measured by two detectors controlled by Alice and Bob as in the scheme studied by Bell.

Here, that the two particles are entangled in singlet state (total spin 0) means that their spins point in opposite directions to each other along a SPECIFIC direction with respect to the detectors. It should be stressed that this direction exists but we do not know it. What we know is that it will be the direction that optimizes the path, not for one, but for both particles (since that is the premise considered at the beginning). We are not making considerations on how the entangled state was constructed at the source. That would correspond to the past but could be significant to the actual orientation of the spins. We simply assume that it is there and was not created in any particular way. Therefore, the angle is, in principle, a free unconstrained parameter also to be included in the minimization process.

Since there is no absolute angle reference we will take Alice's detector as the reference, and we shall call α the angle, yet to be determined, between the particle from the entangled pair going towards Alice and Alice detector. Therefore the angle between the particle from the pair going towards Bob and Bob's detector will be $\alpha - \phi$.

Optimizing the value of the two particles implies that the product of the two factor chains:

$$\omega_{A0}\omega_{A1}...\omega_{A\infty} \times \omega_{B0}\omega_{B1}...\omega_{B\infty} = e^{-(S_{A0}+S_{B0}+...+S_{A\infty}+S_{B\infty})} \tag{11}$$

will be maximal.

Each of the particles will first go through one of the two detectors that are rotated a certain KNOWN angle ϕ respect to each other. Then the particles continue their ways going through many others detectors whose orientation is UNKNOWN.

Each particle will be incident on a detector, one controlled by Alice and other one by Bob, and will be measured. This step correspond to ω_{A0} and ω_{B0} factors. We know the relative angle ϕ between these two detectors because Alice and Bob agree on how to place them, but the rest of the detectors are out of their control and also affect the measurement.

Since there is no absolute angle reference we will take Alice's detector as the reference, and we shall call α the angle to be determined between the entangled pair and Alice detector. Therefore the angle between the particle from the pair going towards Bob and Bob's detector will be $\alpha - \phi$.

To determine the measurement outcomes for Alice and Bob in a particular random case, we should calculate all the possible paths for both particles. Then, find the two paths for each particle that, together, gives the minimum for S for any value of the angle α. Then see what case they correspond for the possible measurements outcomes for Alice and Bob, this is.

There are 4 possibilities for the outcome: Alice measures + and Bob +, Alice measures - and Bob +, Alice measures - and Bob - and Alice measures + and Bob -.

If we neglect the possibility of the crossover of alice and bob's particles in the future (this seems reasonable if the detectors are far away from each other) we should generate 4 different factors from 4 different runs of $\Omega(\infty)$. Let us call them: Ω_{A+}, Ω_{A-} , Ω_{B+} and Ω_{B-}). They represent the value of the path of particle measured by Alice if it chooses +, if it chooses -, and the same for Bob. Then the 4 possible combined outcomes can be expressed:

1. Alice measures + and Bob +: $W_1(\alpha) = \alpha(\alpha - \phi)\Omega_{A+}\Omega_{B+}$.
2. Alice measures + and Bob -: $W_2(\alpha) = \alpha(1 - (\alpha - \phi))\Omega_{A+}\Omega_{B-}$.
3. Alice measures - and Bob +: $W_3(\alpha) = (1 - \alpha)(\alpha - \phi)\Omega_{A-}\Omega_{B+}$.
4. Alice measures - and Bob -: $W_4(\alpha) = (1 - \alpha)(1 - (\alpha - \phi))\Omega_{A-}\Omega_{B-}$.

We know that the trajectory for the two particles will be the path defined by $P[\#X]$ so that

$$\#X = \max[\#1, \#2, \#3, \#4] = \max[\max_{\alpha}[W_1(\alpha)], \max_{\alpha}[W_2(\alpha)], \max_{\alpha}[W_2(\alpha)], \max_{\alpha}[W_2(\alpha)]] \; \forall \alpha \in [0, 1]. \quad (12)$$

If, using brute force, we repeat and average this process until infinite and clasify by cases, we would separately sum up the chances of getting ++, +-, -+ and −.

To calculate the relative probability of correlated vs. uncorrelated measurements as Bell did we have to respond to the question: What is the probability,

$$\mathbb{P}(\#X = \#1 \cup \#X = \#4), \quad (13)$$

that the maximum occurs for cases #1 or #4 vs. that it occurs in #2 or #3? As in the previous case, I haven't been able to compute this so far.

5 Conclusions, considerations and 'summonings'

The first purpose of this paper is to show that this approach can lead to quantitative predictions beyond mere interpretation, even though some assumptions are required to fully fix the model. To draw strong conclusions I should be able to compute exactly the probabilty distribution of $\Omega(\infty)/\Omega(\infty)$ and, so far, I have not been able. Even when I am aware that this basic sketch is not built on a solid foundation, I sense that the result of this simple computation can be enlightening: Falsifying this hypothesis from measurements seems complicated due to its all-embracing and holistic nature, but the mathematical result on 10 and 13 could solidly support or rule out the idea:

- If the result is that $\mathbb{P} \to 1/2$ or is independent from θ_0, then the theory is essentially wrong unless further dynamical considerations are left.
- If the result is that $\mathbb{P} \to \frac{1-\cos(\pi\theta_0)}{2}$, then it seems this is really onto something.
- If the result is a well-defined function of θ_0 or ϕ, then, although the model as presented do not work properly, there is some hope for an improved version of the model to reproduce experiment.

Of course, numerical computer calculations can be undertaken but due to the highly unstable nature of the Ω function it is difficult to delimit their significance. Since the starting point is the definition of abstract angles, I believe this idea could be developed in the framework of Spin Networks [Pen71], but there can be other suitable frameworks unknown to me. I call therefore for any help, wheter it is for performing calculations or for building up a more formal background.

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References

[EPR35] A. EINSTEIN, N. ROSEN and B. PODOLSKY, Phys. Rev. 47, 777 (1935).

[Bel64] Bell, JS (1964), "On the Einstein-Podolsky-Rosen paradox," Physics 1, 195–200.

[Fey65] Feynman, R. P., Hibbs, A. R. (1965). Quantum mechanics and path integrals. New York, NY: McGraw-Hill

[Pen71] R. Penrose, Theory of quantized directions, handwritten notes (1971)