

## **Non-locality in the AB-time interpretation of quantum mechanics**

“How does the [quantum] universe know when to apply unitary evolution and when to apply measurement?” (Aaronson, 2020).

The theory of time in this paper supposes that unitary evolution applies when two systems do not share the same A-series, and a quantum measurement applies when the two systems come to (or 'become to') share the same A-series.

### **Basic statement of the non-locality issue**

The electrons in a superposition from a pair created in the singlet state are sent to space-like separated systems 'Alice' and 'Bob' through a Stern-Gerlach device. Alice and Bob interdependently decide on the relevant orientation of their detectors and measure the spin of (an) electron that comes through their respective device. Quantum mechanics predicts that Alice and Bob get non-local correlations in their measurement outcomes and indeed non-locality has been experimentally verified under different physical assumptions (Wikipedia 2018).

One common way to state things is to say that the electrons in the pair do not have particular spins 'until' detection by Alice or Bob. The crucial word is 'until' which we will unpack below. Apparently there is an interpretation of quantum mechanics using both McTaggart's A-series and his B-series that naturally accommodates this 'until-ness' and thus the non-locality. We reproduce a simple quantitative argument for non-locality due to Mermin, (Wikipedia 2020).

### **A-series and B-series**

For the purposes of this paper, define McTaggart's A-series as that series that 'becomes' from a selected system's future into its present and then into its past. We define the B-series as that series that runs from earlier times to later times. The A-series and the B-series can be varied independently, depending on the situation, so cannot be the same series.

In all of this paper we do not assume that a selected quantum system is macroscopic nor that it is conscious to the extent humans are conscious. This is not a 'human consciousness causes collapse' theory. This is a 'joining of the respective A-series' causes (or is correlated to) collapse theory. Each microscopic closed quantum system has its own A-series (as well as a B-series).

### **A-series $\tau$ and B-series $t$**

Let  $\tau$  be a real variable that runs from a selected system's future into its present and then into its past as in McTaggart's A-series. We may define a unit,  $e$ , that coordinatizes  $\tau$  the way seconds coordinatize McTaggart's B-series earlier-times to later-times ( $e$  is not the electric charge in this context). By convention we will suppose that  $\tau > 0$  means the (A-series) time is in the selected system's future,  $\tau = 0$  is in its present, and  $\tau < 0$  is in its past. This can be generalized to a presentism function  $p(\tau)$  over some non-infinitesimal part of  $\tau$ .

In this paradigm there must be some way to handle the constraints imposed by relativity. To do this suppose that an A-series is associated with each physical system the way that ontologically private qualia are associated with each physical system in Panpsychism (this is not macroscopic human consciousness) (Appendix 1, SEP 2020). Thus one system has an A-series  $\tau$  and a different system has

an ontologically different A-series  $\tau$ '. The B-series are well-defined for time-like separated events in each system.

### The interpretation

There is philosophical motivation for the idea that quantum observation of a system happens when and only when the A-series of the quantum system comes *becomes* to combine with the A-series of the reference system, (Appendix 1) The 'now' of the quantum system combines with the 'now' of the reference system into one 'now'. Thus, in Alice's perspective, Alice measures the spin in a direction of (an) electron when and only when the A-series of Alice and the A-series of the electron-pair become one A-series. Before observation, there is *no fact of the matter* as to whether the 'now' of Alice is the 'now' of the electron-pair. Thus, the spin does not decide—so to speak—which definite value to take on until there is a 'now' of the combined Alice-pair system. The 'until' here is an A-series notion.

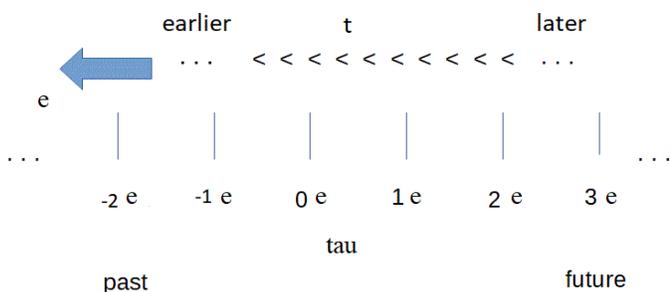
The non-local move here is that the electrons are not independent and space-like separated before observation. This dependence would have to be in Alice's *past* and equally in the pair's *past* but these pasts do not have simultaneous values. There is no fact of the matter 'when'—in Alice's A-series—the electrons are, if their time is a function of their own A-series. From the ontological perspective of Alice, the electron-pair simply did not have the relevant properties *before* observation, and *vice versa*.

It might at first seem odd to propose two quantum systems do not share the same A-series, or the same 'now', until 'mutual' observation. But this is less odd than the notion that there is *no 'now'*--even for a particular selected microscopic system—which is one of the received implications of special relativity. Moreover, this proposal has a solid philosophical motivation (Appendix 1), in sharp contrast to the other realist interpretations of quantum mechanics on the table as of this writing (which I take to be Many-worlds, GRW, de Broglie-Bohm, and Retro-causality, (IEP 2020).)

The following argument is often made. For changes in relevant motions of a spaceship in this galaxy, the planes of simultaneity change for events in (for example) the Andromeda galaxy. But this argument can be turned around. For changes in relevant motions of a spaceship in the Andromeda galaxy, its planes of simultaneity for events in this galaxy change. Yet we do not find that our (and thus each microscopic system's) 'now' goes back and forth 'in time' depending on the movements of the spaceship in Andromeda. The A-series seems to go in only one direction: future into the present and then into past.

Here is a picture of one dimension of AB-series time for one selected system:

**Diagram 1**



As later and later B-series times *become* from the future into the present and then into the past in the A-series, time goes on.

### Notes on perspectival ontology

In this theory a measurement from a system E on a quantum system Cat is in fact a mutual measurement between E and Cat. This is similar to several interpretations.

“The notions of observing system and observed system reflect the traditional notions of observer and system (but any system can play both roles here).” (Rovelli 1996). “This illustrates the fact that in the case of an entangled state between two systems, the perspectives of an external observer who measures one system and the observer who measures the other can generally not be glued together to give us the perspective of the system that consists of both observers.” (Dieks 2019).

We do not assume that any of these systems are macroscopic nor conscious, but for conceptual reasons it will be convenient to state things in terms of the Schrodinger's Cat experiment in this section.

Suppose that for an experimenter E, Schrodinger's Cat is in the state

$$(1) \quad |\Psi\rangle = c_1 |\text{will find cat purring}\rangle + c_2 |\text{will find cat meowing}\rangle$$

in a Hilbert space H. We will assume quantum mechanics is universal, in which case every physically instantiated system must be able to describe (so to speak), *other* systems via quantum mechanics (complications arising from field theories will not distract us in this note).

Therefore, as described by Cat, E is in an analogous state

$$(2) \quad |\Psi''\rangle = c_3 |\text{will find E that finds cat purring}\rangle + c_4 |\text{will find E that finds cat meowing}\rangle$$

in a different Hilbert space H". The long-run statistics of the first and second terms in (1) and (2), respectively, must be the same, so in view of the Born rule we have

$$(3) \quad |c_3|^2 = |c_1|^2 \quad \text{and} \quad |c_4|^2 = |c_2|^2$$

The state-vector  $|\Psi\rangle$  collapses upon observation of Cat by E, and equivalently the state-vector  $|\Psi''\rangle$  of E by Cat collapses upon (mutual) observation. In the interpretation of this paper, at observation and only at observation the A-series of E and the A-series of Cat become the same A-series at mutual observation

### Quantitative agreement with Mermin's example of non-locality

We closely follow Wikipedia (2020a). Suppose that Alice describes—so to speak—and electron-pair as being in state

$$(4) \quad |\Psi\rangle = c_1 |01\rangle + c_2 |10\rangle$$

This form presupposes a basis but  $|\Psi\rangle$  can be written in the basis of any relevant spatial orientation.

Suppose now that Alice's and Bob's detectors are at  $\pi$  rad relative to each other. Then when they measure the spins they will get a 100% correlation. For a second experiment suppose that after the electrons are fired but before the spins are measured Alice turns her detector by  $\theta = 1$  rad. The correlation of the spins will be less than 100% by some small amount  $f_1$ . For a third experiment suppose Alice does the same as in the second experiment and Bob does the same as Alice but rotates his detector in the opposite way from Alice by 1 rad from the anti-aligned detector position. Then if the electron pair had spins before observation by Alice and Bob we would have a maximum deviation of  $2 \times (\theta \text{ deviation}) = 2f_1$  for the local case.

But in the AB-time theory it is trivial to violate this. The electrons do not possess definite spins for Alice or Bob until their A-series become one, i.e. until observation. Thus there is a 2 rad deviation from the anti-aligned detectors at the observations and not two 1 rad deviations. Before observation there is no universal 'now' in which the 1 rad rotations have taken place. We could choose any function we want because we are talking about the correlation at 2 rad and not two correlations at 1 rad. We may take the deviation at 2 rad to be  $f_2 = (2\theta)^2 = 4f_1$ . But we have just argued that the classical case has a maximum violation of  $2f_1$ . In fact  $f_2$  is the value given by quantum mechanics. QED.

## Conclusion

A Bell electron-pair does not take on the pair of values of spins 'until' Alice measures one of the electrons and *visa versa* because the A-series *past* of Alice is not the same as the A-series *past* of the electron system. In the theory of this paper, this 'until' is the point at which the A-series 'now' of Alice and the A-series 'now' of the electron-pair become one A-series 'now'. This makes it trivially easy to get non-locality in the physics.

The AB-time interpretation has virtues. It passes the test of agreement with macroscopic experience. It takes into account both the A-series and the B-series for each system. And it is motivated by being the implication of a plausible philosophical argument. No other realist interpretation on the table as of this writing has philosophical motivation over-and-above the minimal requirement of being consistent with quantum mechanics.

## References

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## Appendix 1

In Dualism it is a hopelessly frequent observation that my 'green' might not be the same as your 'green'. More precisely, if I see some leaves and green qualia arise in my mind and if you look at the same leaves, then I don't know for sure if the qualia that arise in your mind are what I would call green, and *vice versa*. There is *no fact of the matter* as to whether we see the same 'green'. (It's irrelevant if we actually do see the same green—the point is there is an ontic state that contains both of our greens.) Now migrate this observation to each physical closed system, no matter how microscopic. This is Panpsychism where there is no fact of the matter as to whether the qualia associated with one system are the same as the qualia associated with another system. (It might turn out that the assumption of Panpsychism has to be relaxed to—for example—the idea that qualia are associated with the complexity of a system, but the same basic idea applies.)

Since at least Heraclitus it has been observed that the flow of time (the A-series) is (or is like) what we would now call phenomenal consciousness, i.e. qualia. This is a robust observation for the presentist. Thus we have the obvious hypothesis that the A-series of one system is not the A-series of another system. There is *no fact of the matter* whether the 'now' of one system is 'at the same time as' the 'now' of the another system. But clearly there must be just one 'now' when the two systems come together to form one system. QED.

