THE POST-DETERMINED BLOCK UNIVERSE

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By starting from the assumption that the time evolution of a quantum system is always unitary, I arrive at a type of block universe which is different from both the standard one, and from the evolving one.

In fact, the unitary time evolution of quantum systems is not an additional assumption, it follows from the Schrödinger equation and its relativistic versions. What I do is not to add a new assumption, but to argue that the assumption that unitary evolution is suspended during measurements and replaced by a discontinuous collapse of the wavefunction is not actually proven by experiments, and its acceptance was done too quickly. If we can show that the discontinuous collapse is unnecessary, new possibilities open, including for combining Quantum Theory with General Relativity without sacrificing any of them.

The solutions of Schrödinger's equation are unitary, but when we think about "unitary evolution", we think at two different things. On the one hand, as long as no measurement is made on a quantum system, we can regard the wavefunctions as physical fields. Not fields on spacetime, but fields on the phase space. On the other hand, Born's rule gives a statistical interpretation of the wavefunction, which is consistent with the experiments too. Let us call the first interpretation "ontic", and the second "epistemic" (these notions may be used differently by different authors, but I will stick with the definition that "ontic" means that the wavefunction is a physical field on the phase space, and "epistemic" is the knowledge of probabilities or information). Both positions are correct and mutually consistent, once we realize that they refer to different wavefunctions, as I will explain.

The second view was introduced because quantum measurements don't give the wavefunction, but an eigenvalue of a Hermitian operator which is associated to the quantities that we measure. Consequently, we find the wavefunction in an eigenstate, with a probability given by the Born rule. If there was no such problem of measurement, we could interpret very well the wavefunction as being a field in the phase space, and we would have no measurement problem at all. But when we successively perform two incompatible measurements, it seems that the only way to get both times an eigenstate is if we admit a projection happened between the two measurements, which is taken as a collapse and as forcing on us the idea that the wavefunction is probabilistic.

A quantum measurement requires a measurement device, which is a very large quantum system assumed to behave almost classically. This means that we ignore its true quantum state. We also assume that quantum measurements are sharp, which was proven by Wigner to hold only approximately [13, 3]. However, can we make such a strong statement, which amounts to suspending one of the most successful equations, given that the true quantum state of the measurement apparatus is ignored, and that in fact no truly sharp measurement can be made? Why would the evolution be always unitary, no matter for what systems, only to be violated during quantum measurements?

A discontinuous collapse leads to several problems. The conservation laws are due to the commutativity of the operators with the Hamiltonian, but they don't commute with the projectors invoked during measurement. In fact, simple thought experiments show that conservation laws are broken, no matter how we interpret the wavefunction, and this happens even in the Many Worlds Interpretation, for each single world [12]. Moreover, a discontinuous collapse introduces problems with General Relativity, since it implies that also the stress-energy tensor associated to the field collapses, hence, by Einstein's equation, the geometry of spacetime becomes discontinuous, and the covariant derivatives infinite, which is more than unpredictable.

Fortunately there is a way by which unitary evolution is preserved also during measurements, such that the recordings are still consistent with the experiments [7, 11, 12] [1]. This of course should take into account the low-level interaction between the observed system and the measurement device.

However, unitary evolution implies the necessity that the initial state of the observed system and that of the apparatus are in a special relation, even before they interact [9]. The initial conditions for which this works form a zero-measure subset of the Hilbert space! Now this can be seen as "retrocausality" or "superdeterminism". But we know from Bell's theorem that we have to choose between nonlocality and statistical independence (the second option

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[1] Schulman proposed that this may be ensured by imposing that the initial and final states of the universe are separable [4, 5], which is not the position taken here.

was coined by Bell "superdeterminism"). For someone who prefers that the state of the universe is determined (even though unknown) at each instant, in particular for a *presentist*, nonlocality may seem acceptable. But for a relativist nonlocality may be unacceptable. All dynamical equations, including Schrödinger's and its relativistic versions, are local, since the interactions involved are local (although the states can be entangled). Nonlocality will seem at odds with relativity, but assuming that the initial conditions are very special somehow is still consistent with locality and with special and general relativity. The block universe comes to rescue.

We tend to see the dynamics as determined by the initial conditions and the evolution equation. However, in some cases there are obstructions to the existence of global solutions for most initial conditions. When topology is involved, these obstructions imply that not all initial conditions lead to global solutions. A simple example comes from finding all holomorphic functions on a sphere, where the mere topology of the sphere combined with the Cauchy-Riemann equations lead to a drastic reduction of the possible global solutions, allowing only the constant ones.

The study of these obstructions on the existence of global solutions is done in *sheaf theory*, in particular in *sheaf cohomology* [2]. We don't know at a fundamental level what quantization is, we only know recipes to get quantum theories out of classical theories. We don't fully know the topological implications of the various bundles involved in gauge theory, neither the topological properties of particles, but there are indications that they may be relevant. When we will have such a theory, we will have to take into account the topological obstructions, and see what are the implications on the initial conditions. Then, in such a theory it may be the most natural thing to assume what for a presentist looks like "superdeterminism" or "retrocausality". This possibility was proposed in [8, 10].

This kind of block universe is deterministic, but it is not predetermined in the usual sense. The initial conditions are determined with a delay, by each new measurement and each choice of what to measure. The requirement of global consistency implies a severe restriction of the solutions of the Schrödinger equation, but since the observers can choose what to measure, it looks like they determine the past initial conditions more, with each new choice. The solution is still deterministic, but it is determined by future choices. We can still think at this as superdeterminism or retrocausality, if we assume that the initial conditions are fixed from the beginning. But we can also take the stance that the quasi-classical limit, which is a coarse graining of the low-level quantum state, evolves by usual causality in an indeterministic way. As observers, we start with the full set of quantum states consistent with the macroscopic observation, and then reduce them as new measurements provide more information. And since we never know the true quantum state, but only outcomes of our observations made on subsystems, these observations allow us to predict only probabilities, or an epistemic wavefunction which is an approximation of the ontic wavefunction. Moreover, this combination between choice and determinism has implications about free will [6, 10, 1].

By eliminating the discontinuous collapse, we remove an important obstruction which seemed to put quantum theory and general relativity at odds with each other. The so-called *semi-classical gravity* can now be more than an approximation of a future theory of quantum gravity. With an ontic wavefunction, the "expectation value" of the stress-energy operator is not a probability, but a field, and we can plug in into Einstein's equation and get a well-defined classical geometry.

This type of block universe is as deterministic and fixed as the standard one from the bird's eye view of someone who knows completely the ontic wavefunction of the universe. From the point of view of someone who is part of the universe itself, like us, it may look as a growing block universe, with the amendment that the growth is not only towards the future, but at quantum scale it is also towards the past, giving the impression of retrocausality. But this retrocausality is not accessible to us to send messages into the past or at a distance, being forbidden by the fact that we only have clearance to approximate eigenstates, and not to the full quantum state of the observed systems.

References

[1] Scott Aaronson. The Ghost in the Quantum Turing Machine. *"The Once and Future Turing: Computing the World," a collection edited by S. Barry Cooper and Andrew Hodges (in press)*, 2013. arXiv:1306.0159.

[2] G.E. Bredon. *Sheaf theory*, volume 170. Springer Verlag, 1997.

[3] P. Busch. Translation of "Die Messung quantenmechanischer Operatoren" by EP˜ Wigner. *Arxiv preprint quant-ph/1012.4372*, December 2010. arXiv:quant-ph/1012.4372.

[4] Schulman, L.S. Definite measurements and deterministic quantum evolution. *Phys. Lett. A*, 102(9):396–400, 1984.

[5] Schulman, L.S. *Time's arrows and quantum measurement*. Cambridge University Press, 1997.

[6] O. C. Stoica. Flowing with a Frozen River. *Foundational Questions Institute, "The Nature of Time" essay contest*, 2008. http://fqxi.org/community/forum/topic/322, last accessed March 22, 2018.

[7] O. C. Stoica. Smooth quantum mechanics. *PhilSci Archive*, 2008. philsci-archive:00004344/.

[8] O. C. Stoica. Global and local aspects of causality in quantum mechanics. In *EPJ Web of Conferences, TM 2012 – The Time Machine Factory [unspeakable, speakable] on Time Travel in Turin*, volume 58, page 01017. EPJ Web of Conferences, September 2013. Open Access.

[9] O. C. Stoica. Quantum measurement and initial conditions. *Int. J. Theor. Phys.*, pages 1–15, 2015. arXiv:quant-ph/1212.2601.

[10] O. C. Stoica. The Tao of It and Bit. In *It From Bit or Bit From It?: On Physics and Information*, pages 51–64. Springer, 2015. arXiv:1311.0765.

[11] O. C. Stoica. On the wavefunction collapse. *Quanta*, 5(1):19–33, 2016. http://dx.doi.org/10.12743/quanta.v5i1.40.

[12] O. C. Stoica. The universe remembers no wavefunction collapse. *Quantum Stud. Math. Found.*, 2017. arXiv:1607.02076.

[13] E.P. Wigner. Die messung quantenmechanischer operatoren. *Zeitschrift für Physik A Hadrons and nuclei*, 133(1):101–108, 1952.