The present situation in quantum mechanics and the ontological single pure state conjecture

http://tph.tuwien.ac.at/∼svozil/publ/2012-cagliari-IQSA12-pres.pdf
http://arxiv.org/abs/1206.6024 (v2 from tomorrow on)

Karl Svozil

University of Technology Vienna, Austria
vistiting
The University of Cagliari, Italy
The University of Auckland, New Zealand
svozil@tuwien.ac.at

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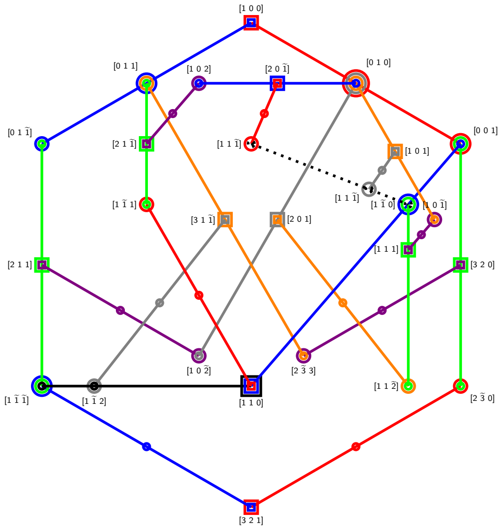
Corollary

Let a and b be two observables that project onto one-dimensional subspaces A and B of the Hilbert space $\mathbb{C}^3$. Suppose there are unit vectors $|a\rangle \in A$ and $|b\rangle \in B$ such that $\sqrt{\frac{5}{14}} \leq |\langle a|b\rangle| \leq \frac{3}{\sqrt{14}}$. Then there exists a set of projection observables $\mathcal{O}$ containing a and b, and a set of contexts $\mathcal{C}$ over $\mathcal{O}$, such that there is no admissible assignment function under which $\mathcal{O}$ is non-contextual, a has the value 1 and b is value definite.

Advertisement for a paper by Abbot, Calude, Conder & K.S., eprint arXiv:1207.2029, Greechie diagram of proof



Persistent issues

Quite rightly quantum mechanics has been lauded as one of the most successful physical theories ever developed by human thought. Yet at the same time non-negligible areas of its formalism, let alone its interpretation, remain conceptually fuzzy and unclear. In this respect, the situation is not too different today than it has been almost a century ago, when Schrödinger published his famous series of articles on the conceptual difficulties troubling the formal framework which he had helped to create.

Do measurements exist?

The late Bell sarcastically observed that, just as Dirac, most quantum physicists appear to be "why bother?'ers" who might just as well neglect the measurement problem by considering it solved "for all practical purposes" (FAPP). Yet, the associated issues are much more pressing now then ever, as technologies based on quantum concepts of measurement have been applied for experiments, as well as deployed for cryptanalysis and industry. In particular, at stake is the nature of randomness emerging from such devices.

Quantum jellification

Already around 1935, Schrödinger considered the *coherent superposition* $|0\rangle + |1\rangle$ of classically distinct, mutually exclusive and operationally separable states $|0\rangle$ and $|1\rangle$, which is a direct consequence of the linear vector space formalism, as a serious issue. He expressed this metaphorically by a cat in a *coherent superposition* "between being dead and alive" $|D\rangle + |A\rangle$; the latter state being somehow "induced" by the coherent superposition of a single two-state quantum by some unspecified but supposedly hypothetical quantum evolution

$$|0\rangle + |1\rangle \mapsto |D\rangle + |A\rangle$$

"blowing up" the microscopic coherence into the classical domain.

Quantum jellification cntd.

In 1952, Schrödinger maintained that, quite generally, without measurement, quantum theorists should be troubled that, due to coherent superposition resulting in the co-existence of classically mutually exclusive alternatives, their "surroundings rapidly turning into a quagmire, a sort of a featureless jelly or plasma, all contours becoming blurred, we ourselves probably becoming jelly fish."

Everett and Wigner's observation of a subjective observer-object cut

Around that time, Everett and Wigner observed that, if a unitary (bijective, one-to-one, reversible, Laplacian-type deterministic) quantum evolution were universally valid, then any distinction or cut between the observer and the measurement apparatus necessarily remains not absolute or ontic, but epistemic, subjective and conventional.

Because, suppose that one has defined a cut or difference between an observed quantum and a "quasi-classical" measurement device, one could, at least in principle and if the unitary quantum evolution is universally valid, "draw a larger perimeter." This " 'enlargement" could encompass the entire previous combination, *including* the quantum, the cut, and the measurement device. If the quantum laws are universally valid, such a quantized system should also undergo a unitary quantum evolution. Hence, any "irreversibility" decays into "thin air."

‘Emergence’ of many-to-one from one-to-one functions?

Question

If quantum mechanics is universally valid, and if it is governed by unitary, reversible, one-to-one evolution, how does irreversibility arise from reversibility?

Fromal aspect: 'Emergence' of many-to-one from one-to-one functions?

Question

How can many-to-one-ness possibly 'emerge' from one-to-one-ness?

Suppose (wrongly) a hypothetical many-to-one function $h(x) = h(y)$ for $x \neq y$ exists which would somehow 'emerge' from injective functions. Any such function would have to originate from the domain of one-to-one functions such that, for all functions f of this class, $x \neq y$ implies $f(x) \neq f(y)$ – or, equivalently, the contrapositive statement (provable by comparison of truth tables) $f(x) = f(y)$ implies $x = y$, a clear contradiction with the assumption.

Indeed, the *unitary transformations* on some Hilbert space $\mathfrak{H}$ form a particular permutation group (consisting of those permutations preserving the inner product), which is a subgroup of the *symmetric group* of all permutations on $\mathfrak{H}$.

Empirical aspect: ‘Undoing’ measurements

Question

Is there a principle (and not only practical or technological FAPP) limit to ‘undo’ measurements?

Quantum erasure experiments seem to indicate that, what one calls “measurement,” as well as the cut between observer and object, is purely subjective, epistemic and conventional.

Copying and amplification of a weak quantized signal

Although Schrödinger's cat & jelly metaphors could have been perceived also as a process of *signal amplification*, researchers only cared to think about quantum *copying* or *cloning* in the early eighties of the last century – in response to an (as it turned out erroneous but stimulating) paper claiming to be able to communicate faster-than-light if generic quantum states could be copied. These considerations have also far reaching consequences for the quantum theory of measurement.

(No-)Cloning theorem

It is possible to "copy" an arbitrary arbitrary orthogonal basis/block/subalgebra/maximal observable/pure state (see below) with a particular "copier" $\mathbf{U}_{\mathfrak{B}}$ associated with that basis or state.

By induction, this analysis can be extended to an *arbitrary number of copies* of the original basis $\mathfrak{B}$.

Any such "copier" $\mathbf{U}_{\mathfrak{B}}$ will, however, *fail for all other states* other states or bases $\mathfrak{B}' \neq \mathfrak{B}$.

Amplification of superpositions

Glauber analyzed the "amplification" or "blowing up" of states such as $|0\rangle + |1\rangle$ by explicitly constructing an amplifier which receives its energy through coupling to field modes, representing the many degrees of freedom of a "quasi-classical" device. This quantum field theoretic analysis goes beyond the scope of this review. Its outcome is a situation where part of the information about the original state is retained, but the final quantum state does *not* contain "more" coherence that the initial superposition. There are more particles present after the amplification, and surely the intensity could be made arbitrary high, but the information extractable from the output of the amplifier is not increased by amplifying the signal. The reason for this is the inevitable introduction of "noise" – that is, additional quanta – originating from the field modes used by the amplification process. The underlying process is a multipartite unitary transformation, and thus again is reversible in principle, but FAPP irreversible.

Some FAPP attempts to get rid of jellification

Zurek, Mandel, . . .

Analogues in classical statistical mechanics

Just as Newtonian physics and electromagnetism appear to be reversible, the quantum measurement conundrum is characterized by the reversibility of the unitary quantum evolution. In this respect, it bears some analogy to Loschmidt's reversibility paradox – that, for large isolated systems with reversible laws of motion, FAPP one never observes a decrease in entropy – and Zermelo's recurrence objection – that, as an isolated system will infinitely often approach its initial state, its entropy will infinitely often approach the initial entropy and thus cannot constantly increase – in classical statistical mechanics.

And just as in statistical mechanics, these arguments appear to apply FAPP but need not be strictly true.

What constitutes a pure quantum state?

Principle

A pure state is characterized by the maximal information encodable into a physical system.

Principle

A pure state can formally by represented by
(i) an orthonormal basis. Synonymously one could also define a pure state as
(ii) a maximal operator *from which all commuting operators can be functionally derived, or*
(iii) as a context, subalgebra *or* block, *or*
(iv) as a unitary transform associated with that orthonormal basis.

The epistemic or ontic (non-)existence of mixed states

Question

Is it in principle possible to produce a mixed state from a pure one?

Again, from a purely formal point of view, it is impossible to obtain a mixed state from a pure one. Because again, any unitary operation amounts to a mere basis transformation or permutation, and this cannot give rise to any increase in stochasticity or "ignorance." Since the generation of "ontologically mixed states" from pure ones would require a many-to-one functional mapping, we conclude that, just as irreversible measurements, genuine "ontological mixed states" originating from pure states cannot exist. Therefore, any ontological mixed state has to be either carried through from previously existing mixed states; if they exist.

Challenge

If you dont believe that, then I suggest you come up with a concrete experiment that would "produce" a mixed state from a pure one.

Epistemic or ontic existence of pure but entangled and/or coherent states

"(Dis-)Entanglement through basis changes"

The (non-)existence of quantum value indefiniteness and its purported "resolution" by quantum contextuality

The Kochen-Specker theorem (and related constructions involving non-separable sets of two-valued states, as well as other arguments (e.g. Bell- and Greenberger-Horne-Zeilinger type constructions) denies the simultaneous validity of the following assumptions:
(i) *omniscience, omni-value-definiteness:* the simultaneous co-existence of certain even finite sets of observables and contexts;
(ii) *quasiclassicality among contexts:* different observables (propositions) in the same context (block, subalgebra, maximal observable, state) behave classically; and
(iii) *noncontextuality, context independence:* whenever an observable occurs in some particular but arbitrary context (block, subalgebra, maximal observable, state), then it must have precisely the same unique (truth) value as that same observable in different contexts.

The (non-)existence of quantum value indefiniteness and its purported "resolution" by quantum contextuality - cntd.

Rather than assuming the most obvious conjecture to sacrifice (i) and to assume that certain observables cannot simultaneously co-exist, this is mostly interpreted as indication for failure of (iii), thus giving rise to *contextuality*; that is, as somehow "implying" that a certain observable may yield different outcomes, depending on what other observables are measured alongside of it.

Measurements of violations of classical bounds on joint probabilities (i.e. "Bell inequalities") are then taken to "prove contextuality."

The ontological single pure state conjecture and phantom contexts and observables

Principle

[Ontological single pure state conjecture] At any given time the system is in a single definite pure state.

Principle

[Context translation principle] Any mismatch between the preparation and the measurement results in the "translation" of the original information encoded by a quantum system into the answer requested, noise is introduced by the many degrees of freedom of a suitable "quasi-classical" measurement apparatus.

Star shaped Greechie diagram of “phantom” contexts

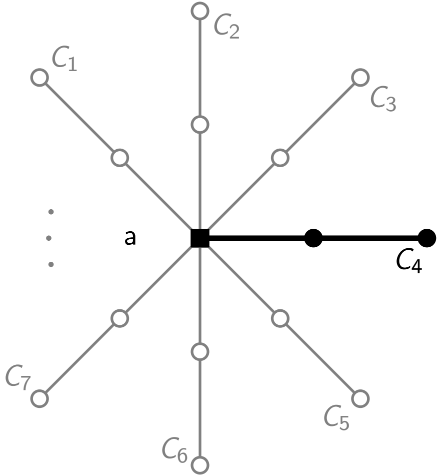
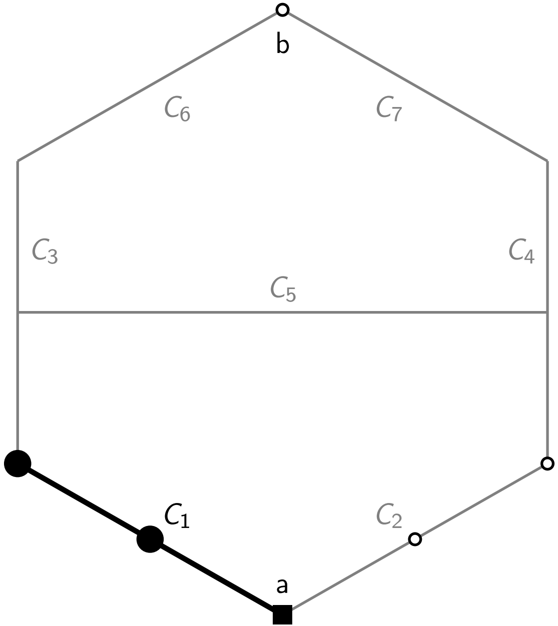


Figure: Greechie orthogonality diagram of a star-shaped configuration, representing a common basis element/projector a with an overlaid two-valued assignment reflecting $v(\text{a}) = 1$. Compare also Abbot, Calude, Conder & K.S., eprint arXiv:1207.2029

Specker's "bug" diagram of "phantom" contexts



Is the best interpretation of the quantum formalism its non-interpretation?

Since around 1920 we are confronted with a situation in which an orthodoxy tries to supress and avoid thinking about the "how" – c.f. Feynman's (in-)famous dictum that while "... nobody understands quantum mechanics," to better stop thinking about these issues "... if you can possibly avoid it. because you will get 'down the drain', into a blind alley from which nobody has yet escaped. Nobody knows how it can be like that."); or at least advises "not worry too much" (cf. Drac) while at the same time expressing the opinion that certain events occur *ex nihilo* (out of nothing), fundamentally inexplicably, and irreducibly random (cf. Zeilinger).

Is the best interpretation of the quantum formalism its non-interpretation?-cntd.

This, I believe, is tantamount to dogmatism, and contradictory to all rationalistic principles on which scientific progress thrives.

I believe that there will be no significant scientific progress in this area without attempts to give meaning to what is formalized. Therefore, interpretation should not be discredited, but considered wisely with *evenly-suspended attention*.

Consequences for quantum random number generators

Where does the quantum randomness reside?

It is often taken for granted, that is miraculously emerges *ex nihilo* from those elements which perform in the Laplacian–unitary regime, such as a beam splitters; but how can this happen?

I suggest to circumvent this conundrum is by postulating that (i) at every instant, only a single state (or context) exists; and that (ii) through *context translation,* in which a mismatch between the preparation and the measurement results in the "translation" of the original information encoded by a quantum system into the answer requested, noise is introduced by the many degrees of freedom of a suitable "quasi-classical" measurement apparatus. This would be an altogether different source of randomness than irreducibly creation *ex nihilo* ("out of nothing") that is favoured by the present quantum orthodoxy.

Thank you for your attention!