Present Situation in Quantum Mechanics

http://tph.tuwien.ac.at/∼svozil/publ/2012-WTCS2012-pres.pdf

Karl Svozil

Institut for Theoretical Physics, University of Technology Vienna,
Wiedner Hauptstraße 8-10/136, A-1040 Vienna, Austria
svozil@tuwien.ac.at

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Schrödinger, E. (1935a). Die gegenwärtige Situation in der Quantenmechanik. Naturwissenschaften, 23, 807–812, 823–828, 844–849. English translation in Ref. Trimmer (1980) and in Ref. (Wheeler & Zurek, 1983, pp. 152–167). http://dx.doi.org/10.1007/BF01491891, http://dx.doi.org/10.1007/BF01491914, http://dx.doi.org/10.1007/BF01491987.

Part I:

Are there quantum measurements?
Can there be quantum irreversibility?
Can there be quantum acausality?

∼ ∼ ∼

Max Born (1926)
http://dx.doi.org/10.1007/BF01397184

. . . the motion of [[individual]] particles conforms to the laws of probability, but the probability itself is propagated in accordance with the law of causality. [This means that knowledge of a state in all points in a given time determines the distribution of the state at all later times.]

2-tier quantum evolution:

*) Everett Process 2: unitary, isometric, one-two-one evolution of the quantum wave function inbetween measurements;

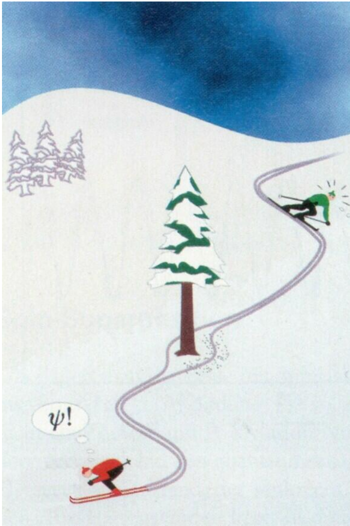
and

*) Everett Process 1: many-to-one state reduction (wave function collapse) upon measurement of single quanta.

The young Schrödinger's uneasyness with Everett Process 2 and the resulting quantum coherence expressed in the aforementioned papers in 1935

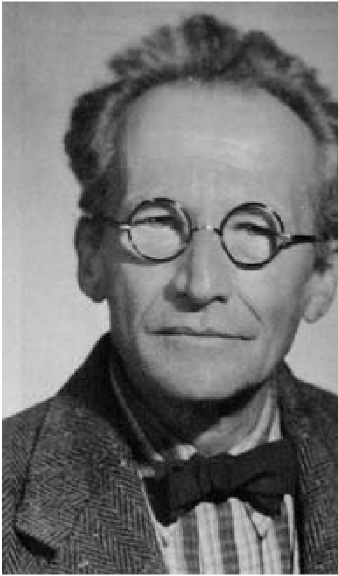
The Cat Paradox & Schrödinger's uneasyness with the coherent superposition of classically mutually exclusive states: how would you experience
*) a "macroscopic" superposition between death & life;
or, alternatively,
*) what would you experience while going through a double slit?!

The production & maintainance of macroscopic superpositions can possibly be assumed to be impossible "for all practical purposes" (fapp, John Bell 1990), but there is no fundamental principle ruling them out.



Schrödinger's Legacy: the 1949-1955 Dublin seminars

The idea that [the alternate measurement outcomes] be not alternatives but all *really happening simultaneously seems lunatic to [the quantum theorist], just* impossible. *He thinks that if the laws of nature took* this *form [[Everett Process 2]] for, let me say, a quarter of an hour, we should find our surroundings rapidly turning into a quagmire, a sort of a featureless jelly or plasma, all contours becoming blurred, we ourselves probably becoming jelly fish. It is strange that he should believe this. For I understand he grants that unobserved nature does behave this way – namely according to the wave equation. . . . according to the quantum theorist, nature is prevented from rapid jellification only by our perceiving or observing it [[Everett Process 1]].*



Hugh Everett (1957): Can there be a Cartesian cut?
http://dx.doi.org/10.1103/RevModPhys.29.454

Consider for example an isolated system consisting of an observer or measuring apparatus, plus an object system. Can the change with time of the state of the total system be described by Process 2 [[unitary transformation, isometry, one-to-one]]? If so, then it would appear that no discontinuous probabilistic process like Process 1 [[measurement, many-to-one]] can take place. If not, we are forced to admit that systems which contain observers are not subject to the same kind of quantum-mechanical description as we admit for all other physical systems.

New experimental input: quantum measurements can be undone, so they are reversible; i.e., one-to-one, and not irreversible, i.e., many-to-one

- quantum erasure experiments (Peres, 1980; Scully & Drühl, 1982; Scully et al., 1991; Zajonc et al., 1991; Kwiat et al., 1992; Pfau et al., 1994; Chapman et al., 1995; Herzog et al., 1995; ...)
- haunted measurements (Greenberger & YaSin, 1989)

Consequences of reversibility for Quantum Random Number Generators

- Quantum components of quantum random number generators – including beam splitters – are, essentially, one-to-one; i.e., reversible, and in this sense causal, with corresponding unitary operator representations.
  For instance, two beam splitters in serial composition yield a Mach-Zender interferometer rendering the initial state; that is, the identity evolution.
- But then, how comes the randomness about?!
- And exactly where and when does randomness emerge?
- Can we trust quantum physical random number oracles based on reversible (state) evolution?
- Cf also Wigner's Friend (1961).

One possible conceptual solution: Context translation principle

- The context translation principle introduces stochasticity and noise through translation of the preparation into the measurement.
- But this noise, although fapp irreversibly generated, again is subject to principal reversibility, so only epistemic and not ontic in nature.

Part II:

What constitutes a quantum state?

Motivation from probability theory

- Bell-type theorems relating to classical correlations polytopes suggest that quantum probabilities are incompatible with classical ones – in the sense that the quantum probabilities violate Boole's *condition of physical experience*. They are, in a certain, weak, sense, empirically falsifyable, and have been tested.
- Greenberger-Horne-Zeilinger theorems suggest that quantum predictions strictly (not only statistically) violate classical predictions. They are, in a certain, weak, sense, empirically falsifyable, and have been tested.
- Kochen-Specher-type theorems imply that there does not exist any global truth assignment (= two-valued measures) on certain finite sets of quantum observables.

What kind of probabilities for different nonboolean algebraic structures?

Requirement: The probabilities for quasi-classical subalgebras should be quasi-classical (Boolean).

- For Hilbert lattices of dimension two ("decaying, unconnected" subalgebras) the problem is unsolved.
- For finite dimensional Hilbert lattices of dimension three onwards ("interconnected" subalgebras), Gleason's theorem identifies the probability measures to be the quantum probabilities governed by the Born rule axiom.
- For finite algebraic structures (such as Wright's pentagram) there exist exotic probability measure which are neither classical nor quantum.

All connections to physics are merely hypothetical. The Born rule is falsifyable and has been tested.

What constitues or defines a physical state?

It is suggested here to define a physical state – different from the usual quantum pure state identified with a (unit) vector or the subspace spanned by that vector or the associated projector – *via* a single unique context.
Contexts represent maximal sets of comeasurable observables, corresponding to maximal observables of the von Neumann (1931) and Kochen-Specker (1967) type [e.g.,Halmos, Finite-Dimensional Vector Spaces, 1974, sect. 84].

Speculations & conjectures

- Physical state is defined by a particular *maximal* set of mutually orthogonal vectors = a context.
  Notice that, in twodimensional Hilbert spaces, fixing a vector fixes the context completely. Not so in higher dimensions!
- Mixed states are merely epistemic constructions, marking our inability to characterize the physical situation completely.
- Ontologically, at any time, the quantized system is in a particular, single context.
  Note that its specification in terms of location in Hilbert space may require an infinite amount of (algorithmic) information.

What if you force a physical system to answer questions it has not been prepared for?

- It may act like a typical Viennese asked by a toureist where the city centre and St. Stephen's Cathedral is: it gives a random, arbitrary answer ;-)
- What is the source of randomness?
  - In the case of the Viennese it may be internal confusion.
  - In the case of the quantum it may be external resources, such as the "macroscopically many" degrees of freedom of the measurement apparatus.

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Part III:

Quantum Entanglement

Open questions

- Why do the quantum correlations are not violating the classical bounds stronger?
- How come there is peaceful existence (Shimony) between relativity and quantum theory despite these “nonlocalities?”

Finally

Happy Birthday, Luminita!!!!

. . . in anticipation:

Happy Birthday, Cris!!!!