

Retrocausality and TGD

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Abstract

This article was inspired by the preprint “Is a time symmetric interpretation of quantum theory possible without retrocausality?” of Leifer and Pusey related to the notion of retrocausality. Retrocausality means the possibility of causal influences propagating in non-standard time direction. The conjecture is that retrocausality could allow wave functions to be real and allow to get rid of the problematic notion of state function reduction.

The work is interesting from TGD view point for several reasons.

1. TGD leads to a new view about reality of wave function solving the basic problem of quantum measurement theory. In ZEO quantum states are replaced by zero energy states analogous to pairs of initial and final states in ordinary positive energy ontology and can be regarded as superpositions of classical deterministic time evolutions. The sequence of state function reductions means a sequence of re-creations of the superpositions of classical realities identified as space-time surfaces. The TGD based view about scattering amplitudes has rather concrete connection with the view of Cramer as I interpret it. There is however no attempt to reduce quantum theory to a purely classical theory. The notion of the “world of classical worlds” consisting of classical realities identified as space-time surfaces replaces space-time as a fixed observer independent reality in TGD.
2. Retrocausality is basic aspect of TGD. Zero Energy Ontology (ZEO) predicts that both arrows of time are possible. In this sense TGD is time symmetric. On the other hand, twistor lift of TGD predicts a violation of time reflection T and this might imply that second arrow of causality dominates in some sense. The ZEO based view about state function reduction essential for TGD inspired theory of consciousness and implying generalized Zeno effect giving rise to conscious entities -“selves” - is also essential. One might say that when conscious entity dies it re-incarnates as time-reversed self.

In the sequel I will discuss the articles from TGD point of view criticizing the hidden assumptions about the nature of time leading to the well-known problems of quantum measurement theory and concrete implications for theories of consciousness.

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1 Introduction

The comments below were inspired by a popular article “Physicists provide support for retrocausal quantum theory, in which the future influences the past” in Phys.org (see <http://tinyurl.com/yd4rws7>) telling about the preprint “Is a time symmetric interpretation of quantum theory possible without retrocausality?” of Leifer and Pusey related to the notion of retrocausality [B3] (see <http://tinyurl.com/yd59jvd5>). Retrocausality means the possibility of causal influences propagating in non-standard time direction. Retrocausality has been also proposed by Cramer as a possible manner to obtain deterministic quantum mechanics and allowing to interpret wave functions as real objects. Bell theorem and Kochen-Specker theorem however pose difficult challenges for this program and the condition that the theory is classical in strong sense (all observables have well-defined values) seems impossible.

The work is interesting from TGD view point for several reasons.

1. TGD leads to a new view about reality solving the basic problem of quantum measurement theory. In ZEO quantum states are replaced by zero energy states which are analogous to pairs of initial and final states in ordinary ontology and can be regarded as superpositions of classical deterministic time evolutions. The sequence of state function reductions means sequence of re-creations of the superpositions of classical realities. The TGD based view about scattering amplitudes has a rather concrete connection with the view of Cramer as I interpret it. There is however no attempt to reduce quantum theory to a purely classical theory. The notion of “world of classical worlds” consisting of classical realities identified as space-time surfaces replaces space-time as a fixed observer independent reality in TGD.
2. Retrocausality is basic aspect of TGD. Zero Energy Ontology (ZEO) predicts that both arrows of time are possible. In this sense TGD is time symmetric. On the other hand, the twistor lift of TGD predicts a violation of time reflection T and this might imply that second arrow of causality dominates in some sense. The ZEO based view about state function reduction essential for TGD inspired theory of consciousness and implying generalized Zeno effect giving rise to conscious entities - “selves” - is also essential. One might say that when conscious entity dies it re-incarnates as time-reversed self.
3. The possibility of superposing states with opposite causal arrows [B1] (see <http://tinyurl.com/1tamjbn>) is a fascinating idea and its plausibility is discussed already earlier in TGD framework [L6] (see <http://tinyurl.com/y9tgfxbf>).

In the sequel I will discuss the articles from TGD point of view criticizing the hidden assumptions about the nature of time leading to the well-known problems of quantum measurement theory and consider also the concrete implications for theories of consciousness. Also the empirical evidence for retrocausality is discussed briefly. Contrary to the article the discussion is non-technical: I do not believe that the introduction of technicalities helps to understand the deep conceptual problems involved and possible solutions to them.

2 Retrocausality

In this section I will explain my own view about retrocausality but will not introduce the TGD view yet.

2.1 Retrocausality: with or without real quantum states

Leifer and Pusey use as a starting point the work of Hue Price [B2] (see <http://tinyurl.com/yaa8wogr>), which claims that if quantum states are real and quantum world is time-symmetric then theory must allow retrocausal influences.

What does one mean when one says that quantum states are real? In standard ontology (PEO) this is usually taken to mean that physics is deterministic and universe corresponds to single solution of field equations. This leads of course to conflict with the facts behind quantum measurement theory. State function reductions are not deterministic. This has led to various interpretations such as Copenhagen interpretation giving up ontology altogether and assuming

only epistemology: wave function describes only our knowledge about something, which does not exist. One has paradox.

Retrocausality has been proposed to save the notion of reality as something unique and deterministic. A stronger condition is that all observables have sharp values as in classical mechanics. For Schrödinger amplitudes - which can be seen also as purely classical objects - the observables are defined by expectation values of operators and simultaneous eigenstates of non-commuting observables are not possible and classicality in strong sense fails.

Cramer's transactional interpretation of quantum theory (see <http://tinyurl.com/zpupb8g>) indeed assumes that both causal arrows are possible.

1. To my best understanding this would mean that there are two time evolutions: the usual one from past to future and the retrocausal one from future to past. At some 3-dimensional hyper-surface of space-time these time evolutions would meet each other and be glued together. At this hyper-surface there would be discontinuities. This picture might lead to the standard statistical predictions of quantum measurement theory such as reduction probabilities if the two states would correspond to eigenstates of corresponding measured observables and transition amplitudes are given by Born rule. Note that Cramer's theory is completely deterministic and there is no room for free will.
2. Realism should be consistent with the experimentally verified Bell theorem supporting non-locality of quantum theory made possible by quantum entanglement. The hope is that retrocausality is consistent with Bell theorem predicting correlations between distant measurements not possible to understand in terms of classical probabilities. The key point is the interference of amplitudes which in quantum theory replaces summation of probabilities.
3. There is also Kochen-Specker theorem (see <http://tinyurl.com/q4vb9j5>) stating that it is not possible to have classical description of all quantum observables when their algebra is non-commutative. If realism is taken to mean that all observables have well-defined values then there is no hidden variable theory allowing realism. Even retrocausality can help only if realism is formulated in less demanding manner.

Leifer and Pusey give up the debatable assumption about reality of quantum states and claim of having proved the same result. The article is rather technical and I have not checked the details. Intuitively the result of course looks rather obvious. Of course, it is possible that theory is not fully time-symmetric and there are still retrocausal influences. For instance, the violation of time reflection symmetry and this could make the ordinary causal influences longer lasting than the retrocausal ones.

2.2 Cannot have both time symmetry and no-retrocausality

Leifer and Pusey show that time symmetry and non-allowance of retrocausality leads to a contradiction but they do not assume the reality of quantum states in the sense of PEO. Time symmetry implies that forward and backward processes have same probabilities. Impossibility of retrocausality obviously requires that the probabilities for retrocausal processes vanish.

Intuitively it is clear that time symmetry is more or less equivalent with the possibility of retrocausality meaning possibility of signals propagating in non-standard time direction. There are however many poorly understood issues.

1. What does one mean with signal? How can one conclude that the time evolution of say electromagnetic field corresponds to signal (or influence) in a given time direction? One possibility is that positive frequency photons correspond to signals to future. In quantum field theories (QFTs) positive energy photons correspond to creation operators and negative energy photons to annihilation operators. By $E = hf$ and its generalization positive frequencies correspond to positive energies. This would code for the selection of arrow of time and causality. This selection has nothing to do with thermodynamics and second law. One could call this ontology positive energy ontology (PEO).
2. It is far from obvious whether the time of physicist geometrized by Einstein can be identified with the experienced time is correct. This identification is done also in the work of Leifer and

Pusey. The arrow of time is naturally assignable to subjective time but not to geometric time. Certainly these two times correlate strongly. We can experience subjective time directly but also use physical processes such as oscillators serving as clocks measuring geometric time, and this gives correspondence between the sequence of mental images and the position of the pointer of the clock.

This strong correlation does not justify the identification of the two times. For instance, subjective time seems to have no future, only the moment “Now” is experienced directly, and there are only memories (even sensory ones) about the past. Geometric time has no preferred value and seems to correspond to eternity. There are therefore dramatic differences between the two times but for some reason they are usually identified.

3. Thermodynamics and second law are certainly closely related to subjective time. Thermodynamical predictions in turn rely kinetic theory with various reaction rates deduced from quantum theory. Non-determinism of state function reduction is what gives to the second law basically. Entropy increases due to state function reduction in the direction of time, which corresponds to a direction in which energies (frequencies for photons) are positive. If subjective time and geometric time are not identified this assumption becomes questionable and one can wonder whether the causal arrow is property of Universe or of quantum state only. For instance, could thermodynamical arrow correspond to non-standard arrow of geometric time?

What time symmetry would mean if one does not identify subjective and geometric time? Is there symmetry with respect to subjective or geometric time or both? Could the causal arrow be a property of quantum state? Is it possible to have both causal arrows without conflict with second law or should one generalize second law so that it applies in reverse direction of geometric time for systems allowing retrocausality?

3 The notions of reality and retrocausality in TGD context

Consider next what one can say about the notion reality and retrocausality in TGD framework.

3.1 About the notion of reality in TGD framework

In TGD framework the question about the relationship between geometric and experienced time leads to a new view about state function reduction solving the basic paradox of standard quantum measurement theory and forces to replace the notion of classical reality with quantum superposition of realities. The new notions are “world of classical worlds” (WCW) and zero energy ontology (ZEO).

1. The key question is whether subjective and geometric time are identical. Could it be that these times are not same? If so, one would have two causalities: causality of state function reductions and causality of field equations. Could state function reductions occur between entire deterministic time evolutions rather than tinkering with single time evolution making it non-deterministic?

This would force to give up the idea about single 4-D reality and replace it with a space of realities. In quantum theory one would be forced to speak of quantum superposition of these classical realities. Each state function reduction would re-create the superposition of 4-D classical realities identified as deterministic time evolutions. One would have realism in more general sense: quantum states would quantum superpositions of classical realities giving rise the “world of classical worlds” (WCW). Quantum jumps would allow continual re-creation of classical realities making possible evolution.

2. What does one mean with WCW? The notion of WCW from the view about TGD as a generalization of quantum field theory and string models. One replaces point-like particles with 3-D surfaces, whose 4-D orbits have interpretation as space-time surfaces. This of course means a considerable generalization of the notion of space-time. Particles can be seen as smaller space-times glued to larger space-times looking like particles in a rougher resolution.

Given sector of WCW correspond to the space of space-time surfaces (generalizing particle world lines) inside 8-D causal diamond (CD), which is diamond like intersection of future and past directed light-cones with points replaced with CP_2 . By holography these space-time surfaces are determined by 3-D surfaces at opposite boundaries of CD. To be precise, instead of ordinary holography one has strong form of holography (SH) meaning that 2-D data determine the classical dynamics and also quantum dynamics to high extent.

This view is obviously something new. Classically physical states are not characterized by the initial values - of say coordinates and velocities at *time=constant* snapshot - but by their boundary values at the future and past boundaries of CD. Initial value problem has changed to boundary value problem. One gives initial and final values but only for coordinates, one might say. One has ZEO rather than PEO. This is essential from the point of view of retrocausality.

3. By its infinite-dimensionality WCW Kähler geometry is essentially unique and even the choice of the imbedding space as $H = M^4 \times CP_2$ is unique by twistorial considerations [L7]. One might say WCW as the space of classical realities is the unique reality, maybe one should call it **THE REALITY**.
4. The wave functions in WCW correspond to WCW spinor fields. WCW spinors correspond to many-fermion states at given space-time surface and spinor fields are these spinors extended to spinor fields in WCW. All fundamental particles reduce to many-fermion states. This picture is a completely straightforward generalization of the notion of wave function in Minkowski space obtained by replacing point like particles with 3-surfaces. "Center of mass" degrees of freedom for 3-surfaces indeed are indeed characterized by $M^4 \times CP_2$ -coordinates. These WCW spinor fields can be said to be purely classical spinor fields. There is no second quantization at WCW level. Therefore the only genuinely quantal aspect of quantum TGD would be state function reduction, which makes possible conscious entities with free will and leads to the notion of subjective time besides geometric time.
5. Quantum classical correspondence (QCC) is one of the basic principles of TGD and says that classical physics is exact part of quantum physics. The space-time surfaces in the quantum superposition are preferred extremals of certain action principle. "Preferred" means that SH holds true. In standard path integral approach one would have path integral over all possible space-time surfaces, now only over the preferred extremals. For integrable theories about which TGD seems to be an example, these two views are more or less equivalent. QCC states that the classical Cartan algebra Noether charges for preferred extremals in superposition are identical with eigenvalues of corresponding quantal charges. One could consider even the possibility that all classical Noether charges for the preferred extremals in the superposition are same as the expectation values of their quantum counterparts.
6. Cramer's view about state function reduction as gluing together of causal and retrocausal solutions of field equations together at 3-D surface has a highly interesting analogy in TGD. Elementary particle vertices correspond to this kind of gluing of corresponding space-time surfaces together along their ends [K7, L7]. At partonic level one has analogy of three-particle Feynman vertex. The three external lines of vertex correspond to three 3-D lightlike orbits of partonic 2-surfaces defining boundaries between space-time regions with Minkowskian and Euclidian signature of the induced metric. The vertex corresponds to partonic 2-surface at which these orbits are glued together along their ends. There is also gluing of space-time surfaces along their 3-D ends which could be located to boundaries of a sub-CD within larger CD containing initial and final states of particle reaction at its boundaries. The amplitudes at vertices are obtained using the QFT analog of Born rule.

QCC would require that each space-time surface in the superposition of space-time surfaces in CD satisfies the Cramer type rules for each vertex involving sub-CD. The superposition of space-time surfaces would be superposition of potential state function reductions! The real state function reduction would pick up of them!

To sum up, in TGD there is no attempt to get rid of the non-determinism of state function reduction or force the reality to be classical in the sense of classical mechanics (local realism with

well-defined values for all observables). Classical Noether charges are well-defined for all space-time surfaces but it is impossible to localize WCW spinor field to single space-time surface. This is already impossible by the fact that there is always finite measurement resolution: this notion indeed plays key role in TGD framework and involves p-adic length scale hierarchies and hierarchy of Planck constants labelling dark matter as phases of ordinary matter. Cramer's rule however resembles very strongly the TGD view about classical space-time correlates of particle reactions.

To my view the most precious gift of quantum theory based on ZEO is the possibility to understand free will without conflict with the determinism of basic field equations and various various trying to force old-fashioned reality give up this gift.

3.2 ZEO based view about time, state function reduction, and consciousness

In ZEO quantum measurement theory extends to a theory of consciousness: observer ceases to be an outsider and becomes part of the physical world also mathematically. The detailed discussion of various issues and of recent situation of TGD inspired theory of consciousness can be found in [L8].

The basic idea is that consciousness (actually not a property of anything) is in the state function reduction, between the two quantum realities rather than being a property of quantum reality. This resolves various problems of monistic and dualistic approaches, and one could say that TGD ontology is tri-partistic: classical existence at the space-time level (space-time surfaces), existence at quantum level (zero energy states), and conscious existence at the level of state function reductions. Adelic physics implies further division of realities to "real" and p-adic sectors serving as correlates for sensory and cognitive aspects of conscious experience.

The theory has developed slowly. ZEO meant breakthrough and led gradually through twists and turns to a notion of self surprisingly similar to the original idea. Negentropy maximization principle (NMP) was for a long time regarded as a separate principle but its statistical form follows automatically from adelic physics [L4, L5]. The understanding of the notion of time has been the main challenge.

The basic notion is that of self.

1. Self corresponds to a sequence of quantum jumps integrating to single unit as in the original proposal, but these quantum jumps correspond to repeated state function reductions leaving both the passive boundary of CD and the corresponding parts of zero energy states (state pairs) invariant. The parts of zero energy states at the active boundary of CD change and even the position of the tip of the opposite boundary changes: one actually has wave function over positions of second boundary (CD sizes roughly) and this wave function changes. In positive energy ontology these repeated state function reductions would have no effect on the state (Zeno effect) but in TGD framework there occurs a change for the second boundary and gives rise to the experienced flow of time and its arrow and self: self is generalized Zeno effect.
2. The first quantum jump to the opposite boundary corresponds to the act of "free will" or birth of re-incarnated self. Hence the act of "free will" changes the arrow of psychological time at some level of hierarchy of CDs. The first reduction to the opposite boundary of CD means "death" of self and "re-incarnation" of time-reversed self at opposite boundary at which the the temporal distance between the tips of CD increases in opposite direction. The sequence of selves and time reversed selves is analogous to a cosmic expansion for CD. The repeated birth and death of mental images could correspond to this sequence at the level of sub-selves.
3. This allows to understand the relationship between subjective and geometric time and how the arrow of and flow of clock time (psychological time) emerge. The average distance between the tips of CD increases on the average as along as state function functions occur repeatedly at the fixed boundary: situation is analogous to that in diffusion. The localization of contents of conscious experience to boundary of CD gives rise to the illusion that universe is 3-dimensional. The possibility of memories made possible by hierarchy of CDs demonstrates that this is not the case. Self is simply the sequence of state function reductions at the same

boundary of CD remaining fixed and the lifetime of self is the total growth of the average temporal distance between the tips of CD.

4. It is important to notice that one has actually self hierarchy as a counterpart for the existence of hierarchy of systems. Sub-selves correspond to mental images of self, which in turn defines mental image of a higher level self. The proposal is that sub-selves of sub-self are experienced as averages. One might say that TGD predicts pan-psychism in well-defined sense.

The new view about subsystem makes possible sharing of mental images by entanglement although selves are un-entangled at their own level and thus define separate conscious entities. The new view about subsystem follows naturally from the notion of many-sheeted space-time: space-time sheets can be disjoint although smaller space-time sheets glued to them by wormhole contacts with Euclidian signature of induced metric can have magnetic flux tube connections serving as correlates of attention.

It is clear that selves and their time reversals correspond to causality and retrocausality. Self experiences that signals arrive from geometric past always: the roles of past and future are however changed in the re-incarnation of self.

ZEO can be said to be time symmetric. There is however a breaking of time symmetry in the sense that the twistor lift TGD violates T (and also of CP and P) realized as a time reflection with respect to the center of CD [L2, L3]. An interesting question is whether this asymmetry could favor the second causal arrow in some sense. For instance, could the life cycles of self with standard arrow of time be considerably longer than those for time reversed selves? This would be due to T-non-invariance of the probabilities for the first reduction to the opposite boundary of CD. Could the longevity in standard time direction emerge in long length scales? For elementary particles the durations of selves are expected to be short since the usual rules for state function reduction apply to the reductions meaning death of self.

There are processes in which the arrow of time seems to be non-standard and a fascinating question is whether these ghostly time reversed selves could be observed, and whether even communications with them could be possible! Some people believe in communications between deceased and alive and study of the communications with deceased is part of parapsychology: could there be some seed of truth in these beliefs?

3.3 Possible implications and experimental support for retrocausality

Retrocausality implies that signals can propagate in both directions of time. The signals could even be time reflected at the boundary of CD, which would mean state function reduction changing the arrow of time in the case of signal (note that there is hierarchy of CDs and selves). These reflections could make possible apparently superluminal communications and communication with future and past.

1. The TGD based model for long term memories and precognition relies on the idea that memories involve time reflection from either boundary of CD [K2, K5, K4, K1].

The model for motor actions as induced by signals sent to the brain of the geometric past relies on the same idea and explains Libet's strange finding that conscious action is preceded by neuronal activity [J1] used usually to argue that free will is illusion.

Since the signals propagating to non-standard direction of time has negative energy, one can consider also a model of remote metabolism in which the system needing metabolic energy sends negative energy signal to a system able to provide it, say population reverted laser. This quantum credit card mechanism making possible instantaneous reactions would have obvious evolutionary value and would also favor co-operation.

2. Fantappie [J2] was probably the first theoretical physicist to propose that causal arrow might vary in living matter and introduced the notion of syntropy, which would correspond entropy growing in nonstandard direction of time. There is quite a number of bio-systems which might be retrocausal at some level. One example is the self-assembly of bio-macromolecules (say tobacco mosaic virus): retrocausally a decay would be in question. Also phase conjugate laser beams [D1, D2] and phase conjugate sound waves are known to obey second law in

wrong time direction. For some reason these empirical facts have not captured the attention of theoreticians. In ZEO these findings find a natural explanation.

3. The possibility of time reflection implies that light velocity ceases to be a barrier for communications. One can even speculate with the possibility that conscious entities in distant galaxies could communicate using this mechanism. The altered states of consciousness caused by various psychedelics involve often the experiences about encountering representatives of other civilizations and one can ask whether these encounters are due to remote sensory experiences based on the the above mechanism involving both classical and quantum communication (entanglement) [L1] [K6, K3]. Could it be that some sensory receptors (perhaps all) are connections to magnetic flux tubes which can connect the brain to even remote galaxies? If this were the case, one must ask whether our ideas really originate in our brains.
4. One can even imagine that causal arrow is not definite in the sense that one can have quantum states, which are superpositions of states with opposite causal arrows, and there is even a claim that the existence of these states have been verified experimentally by quantum measuring the arrow of causality - causal witness is the name for this observable: see the article *Experimental verification of an indefinite causal order* by Rubio et al [B1](see <http://tinyurl.com/ltamjbv>). The popular article "*Causal Witness*" Provides First Experimental Evidence Of Indefinite Causal Order (see <http://tinyurl.com/lwaurk3>) summarizes the work of Rubio et al.

If the finding is real it is revolutionary: in the standard physics framework it is very difficult to imagine how a superposition of different causal arrows could be possible. In the case of superposition of two causal orders the measurement of causal witness has two outcomes and both are claimed to be possible with certain probabilities.

Does TGD allow the superposition of causal arrows? One can obviously decompose the sub-WCW associated with given CD to sectors with well-defined causal arrow: they are related by time reflection T and are indeed different by T violation for classical dynamics. The roles of passive and active boundaries would be changed for the T -related sectors [L6] (see <http://tinyurl.com/y9tgfxbf>). Superposition of causal arrows would mean a state having component in both sectors. This makes sense if state function reduction to the opposite boundary is preceded by the measurement of the causal witness. Therefore the formation of this superposition and refusal to measure causal witness would be a recipe for immortality!

The localizations in the sequence of reductions to the active boundary must occur in complete synchrony for the components in the superposition if they occur at all. A stronger condition is that the two reduction sequences cease so that the time flows stop in both directions: there would be no observables commuting with the observables diagonalized at the passive boundary to be measured anymore [L8]. Does the absence of a well-defined causal arrow alone imply an experience of timelessness or must also the time flow stop? Could the enlightened states reported by meditators and involving experience of timelessness have something in common with this kind of states?

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