Generalised Entanglement
Theory and Applications

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Generalised Quantum Theory

- Niels Bohr was convinced that the quantum theoretical structure of complementarity was realised beyond physics. Also W. Pauli, C.G. Jung, W. James,…
- GQT: Minimal formal framework, in which complementarity and entanglement can be well defined
- Sucessive enrichment up to the full quantum theoretical formalism open option
- No physical reductionism but partial structural isomorphy
- Many applications worked out

VQT References

H. Atmanspacher, H. R., H. Walach: *Weak Quantum Theory: Complementarity and Entanglement in Physics and Beyond*, Foundations of Physics **32**, (2002), 379-406

H. Atmanspacher, Th. Filk, H. R.: "Weak Quantum Theory: Formal Framework and Selected Applications" in Quantum Theory: Reconsideration of Foundations-3, AIP Conference Proceedings, A. Khrennikov ed. vol 810 Melville NY 2006

Th. Filk, H. R.: *Generalized quantum theory: Overview and latest developments*. Axiomathes, 21,2:211--220; DOI 10.1007/s10516--010--9136--6, 2011

Generalised Quantum theory

- *System* (identification, isolation, subsystems)
- *State* (not necessarily associated Hilbert space, pure and mixed states)
- *Observable* (Features open for investigation), global and local observables
- *Measurement* (Performing investigation belonging to observable A with result a, which has factual validity)

Observables

- Identification of Observables is a highly creative act
- Associated to every observable A there is a set Spec A, the spectrum of A, the set of all possible outcomes of a measurement of A

Measurement and Eigenstate

- The result of a measurement of an observable A depends on the state of the system but is in general not determined by it
- After measurement of A with result a the system resides in an *eigenstate* z_a, in which a measurement of A yields the result a with certainty. An immediate repetition of the measurement will give the same result a and will not change the eigenstate z_a

Complementarity

- For *complementary* observables A and B measurements are not interchangeable.
- The final state of the system depends on the order in which the measured values were obtained. After measurements the system is in an eigenstate of the last measured observable
- For given measured value a of A there is general no common eigenstate z_{ab} of A und B.
- Thus, in general no common measurement values can be attributed to complementary observables
- This is the essence of quantum theoretical complementarity
- Non complementary observables are called compatible
- Complementarity experimentally testable. Consistent history formulation of QT can be taken over to GQT

Quantum Analogue Behaviour

- “Measurement” changes state, transition from potential to factual: Psyche from first person perspective, discourse systems, “wine tasting”, believe structures, creative acts, decision acts
- Possible complementarities: Rationality vs. creativity, mental vs. neuronal, process vs. substance, goodness vs. justice; quantitative applications to bistable perception and questionnaires (H. Atmanspacher, Th. Filk, H.R.,…)

Fundamentals of Human Existence Implemented in GQT

- GQT simple and natural general structure taking into account
- Figure of "excentricity", "oppositeness", *epistemic cut:* cognition always by someone of something
- "Facticity": World of facts rather than potentialities
- *Temporality* of existence (Movie rather than panorama), related to this
- *Causality* and *freedom* both stem from the same root: Temporality unfolded into past, present and future
- *"Agentivity":* planning and worrying, factum = made

Classical World as Special Case

- Classical theory as a special case of GQT: All observables are compatible, order of measurements does not matter, Simultaneous attribution of values possible for all observables
- This is a strong additional assumption, remember examples. From the standpoint of GQT quantum like theories are more natural, "ontological parsimony"

Propositions 1

- Propositions are observables which correspond to „yes-no“ questions to the system:

$$specP \subset \{yes, no\}$$

Propositions 2

- Define always true proposition **1** and always false proposition **0**
- Define negation P‘ of proposition P (P and P‘ are compatible), P‘‘ = P, **0**‘ = **1**
- For compatible P and Q define conjunction P AND Q and adjunction

  P OR Q = (P‘ AND Q‘)‘; **1** AND P = P,

  P AND P‘ = **0**,…
- Boolean system would give classical theory

Action of Propositions on States

- „Zero state“ o must be associated as in physical quantum theory
- Define P(o) = o and for state z ≠ o

  - P(z) = o, if answer to question P is „no“ with certainty for state z

  -P(z) = the state resulting from measurement of P if answer is „yes“
- **0**(z) = o, **1**(z) = z
- Thus, a product PQ of propositions is defined, and we have PP = P

Compatibility and Commutativity

- Propositons P and Q are compatible if and only if P,Q, P‘ and Q‘ all commute as actions on states, otherwise P and Q are complementary
- For *compatible* propositions P and Q we have P AND Q = PQ

Observables and Propositions 1

- To an observable A and to every a in SpecA we can associate a proposition A_a corresponding to the assertion that a is the value of A. For a proposition P evidently $P_{yes}=P$,

  $P_{no}=P'$
- $A_a A_{a'} = \mathbf{0}$ for $a \neq a'$ and

$$\bigcup_{a \in SpecA} A_a = 1$$

- Conversely, one could start with propositions only and define observables as families of propositions with the above properties

Observables and Propositions 2

Clearly, A and A_a are compatible, and two observables A and B are compatible if and only if all the propositions A_a and B_b are compatible

Differences between QT and GQT

- No quantity like Planck's constant controlling the degree of non commutativity. Complementarity and entanglement may be macroscopic.
- No probability distributions for results of measurements. Only modal qualifications „impossible", „possible", certain". No Hilbert space for states, no tensor products, no addition of observables, no C*-algebra, no GNS-construction. Only propositions act on states.
- No basis for derivation of Bell's inequalities. Indeterminacies need not be of ontic nature. They may be epistemic. (GQT as phenomenological theory); P. Beim Graben, H. Atmanspacher, Th. Filk
- Even in the absence of quantitative features a general quantum theoretically inspired conceptual framework may be instructive, inspiring and fruitful

Towards Full QT-Formalism

The gap between GQT and QT is not too large

- Definition of conjunction for non compatible propositions
- Modularity: P OR (Q AND R) = (P OR Q) AND R for P ≤ R
- Distributivity for every subsystem generated by compatible $P_1 \leq P_2$ and their negations gives full formalism
- Applications of full formalism to bistable perception, questionnaires, psychophysical correlations,… (Atmanspacher, Filk, H.R., Aerts, Primas, Busemeier, Pothos, Uzan,…)

Entanglement between separated subsystems in full QT

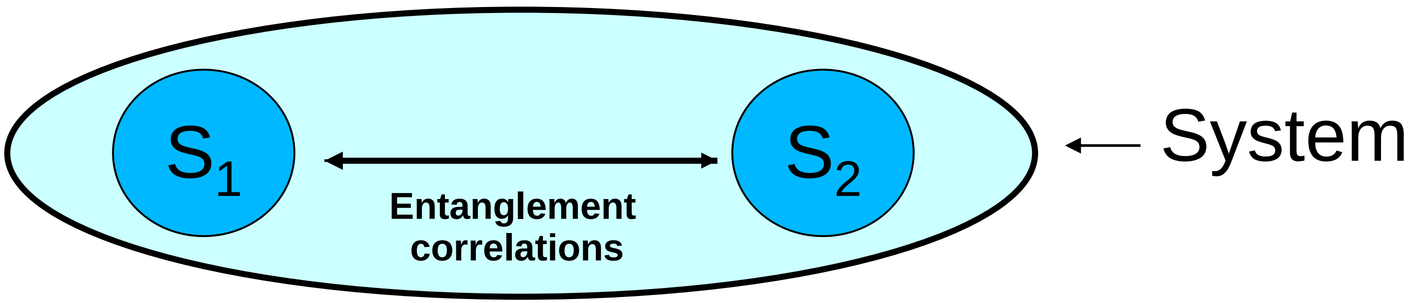
- Total Hilbert space as tensor product of separated components
- Pure entangled state: Not a tensor product of subsystem states
- Mixed entangled state: Not a convex combination of tensor product states
- In any case: Existence of a global observable, which is complementary to local observables pertaining to the subsystems. E.g. projector on entangled state or density matrix interpreted as observable. (Standard example $(\mathbf{s}_1 + \mathbf{s}_2)^2$ vs. $\mathbf{s}_1$ and $\mathbf{s}_2$)

Generalised Entanglement

1. Partition into separated subsystems: Local observables for different subsystems compatible
2. Existence of global observable complementary to local observables
3. Entangled global state, in which values of local observables are undetermined (E.g. eigenstate of global observable). Entanglement correlations as in full QT
4. Product states $(z^{(1)},z^{(2)})$ definable also in GQT, but no superposition principle
5. Axiom NT: Entanglement correlations not usable for signals or controllable causal influences

Conditions 2. and 3. are experimentally testable, at least in principle. 5. is an exclusion criterion against entanglement.

Entanglement



- Complementarity of global and local observables
- For entangled states measurement values for subsystems undetermined, but
- *Entanglement correlations* between subsystems: non local, Einstein's „spooky interactions",not controllably causal, *not usable for signal transmission* (Axiom NT for GQT, necessary to avoid paradoxes)

Entanglement vs. Mixture

- “Black and white balls” as examples for mixed non product states. Axiom NT holds also in this situation but no global-local complementarity
- In quantum physics, inequalities of Bell‘s type allow for a distinction between an entangled state and a mixture of product states and for a decision in favor of the ontic character of indeteminacies, complementarity and entanglement.
- In GQT in its most general form the question for the ontic or epistemic origin of indeterminacies sometimes remains open (GQT as phenomenological theory). Compare H. Atmanspacher: Epistemic Entanglement

Example: Measurement and Cognition

Theory of the measurement process:

Product state of measured system and measuring device

→ Transition to entangled state by causal dynamics

→ Truncation to mixed state of measuring device

→ Reduction to eigenstate of the measured observable, probability determined by mixture

- Correspondence of measured system and measuring device by entanglement
- Uncertainties of measured value by truncation
- Analogously for cognition in VQT

Example: Human Communities

- Therapist – patient: Countertransference
- Special close(d)ness in archaic groups
- Rituals
- Collective mass phenomena
- Parallelism of cultural developments (“axis time”)

Remember phenomenological character of VQT: Uncontollable causal mechanisms not excluded. Effective quantum system may rest on classical foundations.

Generically combination of causality and entanglement to be expected

Example: “Synchronistic” Phenomena

- So-called “paranormal” phenomena
- Homeopathy

Search for stable controllable causal mechanism consistently frustrated. Phenomena of decline, revival and evasion. Option of phenomenological treatment as entanglement correlation.

Example: Aesthetics

- Beauty of an object resides in the interplay of its parts
- Beauty: Neither coercion and strict determination by the whole nor decay into uncorrelated disjoint parts: Interpretation as generalised entangle-ment
- F. Schiller: Beauty as “freedom in appearance”
- Entanglement also with contemplator(s): Reception aesthetics. Necessarily enigmatic character of great works of art.

Résumé

- Entanglement correlations: Non causal order structures as fully legitimate elements of reality
- Entangled state does not fully determine the states of subsystems but leaves freedom to them. Holism resides in correlations
- Phenomenological character of GQT. Axiom NT, but non controllable causal mechanisms not excluded, epistemic entanglement possible, causal and non causal ordering may collaborate
- Even in the absence of quantifiable predictions merits of an alternative conceptional framework should be appreciated.