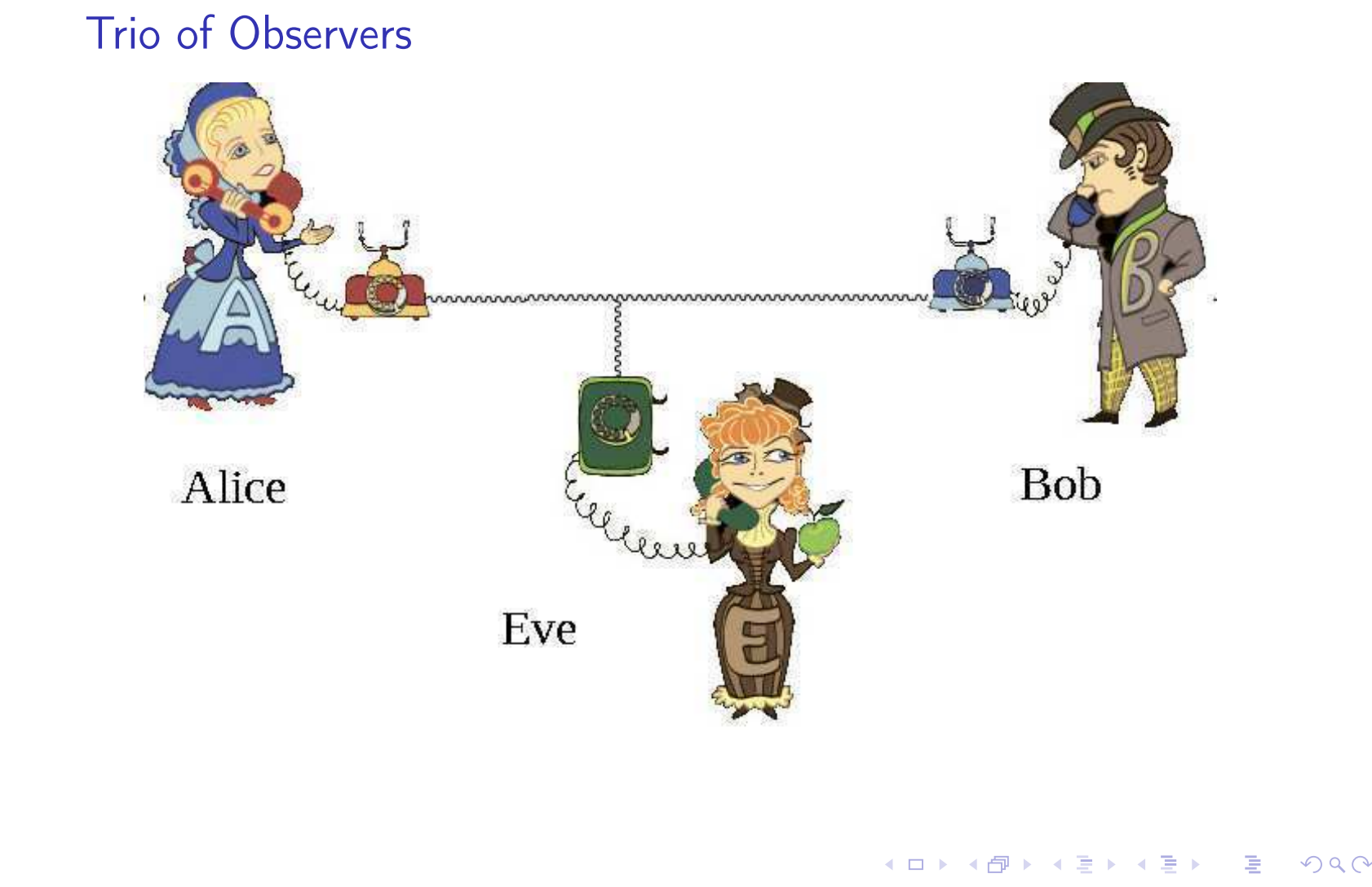


Pragmatic View
on the Measurement of Quanta
How can AI act
as the quantum observer?
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Natural Observers



Observer Components

Source, Meter, Registrar, Controller

- For each measurement act, the Source prepares the Quantum in a given state.
- Meter interacts with the Quantum during some time.
- Registrar records the change in the state of Meter resulting from its interaction with the Quantum.
- Controller plans the sequence of actions for the Source, Meter, and Registrar.

Image and Data

When planning measurement activities, the observer is guided by a personal image of the Quantum. The image is formed on the basis of information received from outside and that accumulated through previous measurements. The Observer may add the information obtained from the measurement to the personal image of the Quantum or disregard it. It is also possible to make the obtained information public, share it with a limited circle of recipients, or retain it exclusively for personal use.

Personal Image of Quantum

The wave function, the state vector or the density matrix are characteristics of the Image, but not of the Quantum itself.
"Probabilities are taken to be degrees of belief instead of objective states of nature". Bruno de Finetti

Wigner's Friend

He may withhold or disclose the measurement results at his own discretion. Before Wigner obtains these results, his prediction regarding the properties of the Quantum is incorrect.

EPR

The observers of entangled electrons can draw conclusions about the measurement results for the other electrons only if no unexpected events involving those other electrons have occurred.

Meter Response

Observables of response

According to the von Neumann projector method, the Hamiltonian of interaction of the Meter with the Quantum is

$$H_I = \sum_{m=1}^{N^{(A)}} R_m |m; A\rangle \langle m; A|. \quad (6)$$

Responses R_m are observables of the Meter, $N^{\{M\}} \times N^{\{M\}}$ matrices. It is assumed that none of the commutators $[R_m, R_{m'}]$ and $[R_m, H_n^{\{M\}}]$ vanish.

Hamiltonian of Meter&Quantum

$$H^{\{MQ\}} = \sum_{m=1}^{N^{(A)}} H_m^{\{M\}} \times |m; A\rangle \langle m; A|, \quad H_m^{\{M\}} = H_n^{\{M\}} + R_m. \quad (7)$$

Source

Definition

Upon the request of Controller, Source prepares a specified pure state $|in\rangle$ of Quantum.

Design

The Source measures the Quantum so that $|in\rangle$ is one of the eigenstates of the Source observable S . If the measurement result is a different eigenstate $|diff\rangle$, the matrix

$$U[diff \mapsto in] = \hat{I} - |in\rangle \langle in| - |diff\rangle \langle diff| + |in\rangle \langle diff| + |diff\rangle \langle in|,$$

performs the required unitary transformation

$$U[diff \mapsto in] |diff\rangle = |in\rangle.$$

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Critique of some Reasons for Skepticism regarding AI Observer

Some Paradoxes

- Paradox of Schrodinger's Cat.
This paradox is resolved through a rigorous definition of probability.
- Einstein-Podolsky-Rosen paradox.
This paradox demonstrates the non-locality of quantum mechanics.
- Wigner's Friend Paradox.
This paradox demonstrates the individual nature of the Image for measured Quantum.

The Problem of Heisenberg Cut

This problem is resolved by formalizing the definition of the distinction between classical and quantum measurement.

Definition of Observer

An observer is defined here as a set of instruments – controlled remotely or via software – that performs all the actions necessary to obtain measurement results and store those in a form suitable for use by third parties.

- Measurement Act consists of interaction between the Quantum and the Meter.
- Statistical Measurement collects the sample as a set of Measurement Acts.
- Measurement of State collects the set of samples with noncompatible Meters.
- In Classical Measurement uncertainty of the initial and final states remains substantial.

Meter

Very large quantum object

The number of the degrees of freedom $N^{\{M\}}$ of the Meter, as a very large quantum object, is large compared to the number of degrees of freedom of the Quantum, $N^{\{M\}} \gg N^{\{Q\}}$.

Uncertainty

The initial state of the Meter remains incompletely defined since to much time is needed to determin it.

Here, it is assumed that the initial state of the measuring device belongs to the subspace $V_{in}^{\{M\}} \subset V^{\{M\}}$ of space $V^{\{M\}}$ of the Meter density matrices.

The dimension of the initial-state subspace $N_{in}^{\{M\}} = \dim V_{in}^{\{M\}}$ determines the maximum possible entropy of the initial state of the Meter.

$$H_{in}^{\{M\}} = \log_2 N_{in}^{\{M\}} \quad (4)$$

Initial state of Meter

$$H_{in}^{\{M\}} = \sum_{m=1}^{N^{\{M\}}} E_m |m; M\rangle \langle m; M|; \quad \rho_{in}^{\{M\}} = \sum_{m=1}^{N^{\{M\}}} p_m |m; M\rangle \langle m; M|. \quad (5)$$

Registrar

Definition

Registrar generates and transmits to the Controller information regarding the approach of the state of Meter to one of the subspaces of the stationary states $V_m^{\{M\}}$.

Example of a procedure

1. Determines the distances $d_m^{\{M\}}$ from the current density matrix of the Meter to each of the subspaces $V_m^{\{M\}}$.
2. Compares all the distances $d_m^{\{M\}}$.
3. If one of the distances $d_{m'}^{\{M\}}$ is significantly smaller than all the others, the index m' is transmitted to the controller as the measurement result.
4. Otherwise, determination of all distances is repeated.

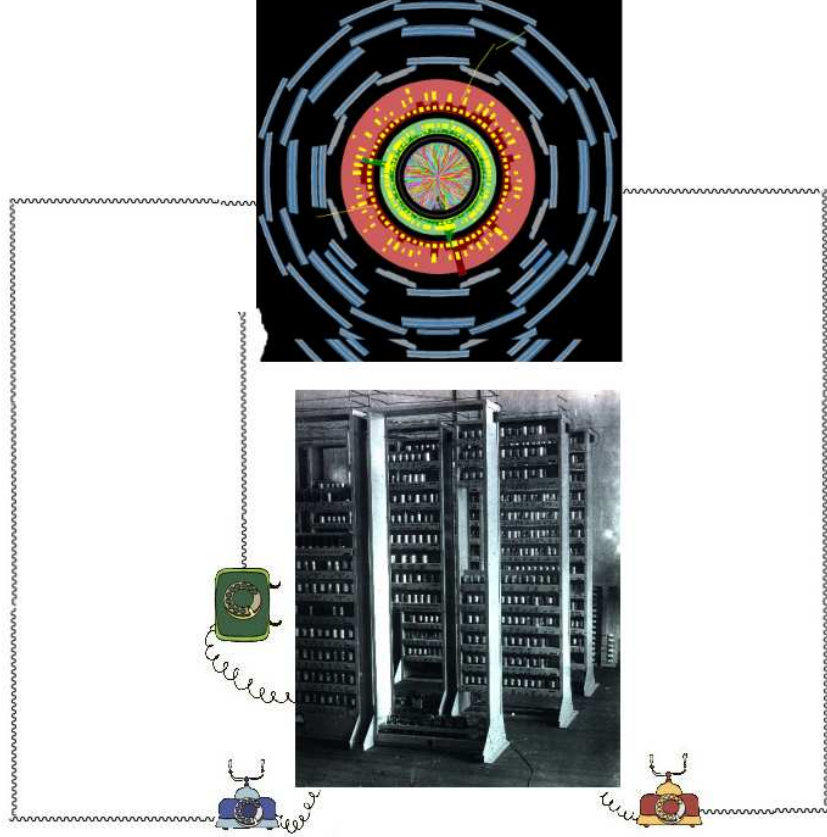
Conclusions

Main Theses

- The results of measurements are generated as private and can be publicized at the discretion of the Observer.
- The Image of the measured Quantum is also private.
- The process of the measurement becomes non-quantum when it consists of a large number of quantum measurement acts.
- The Heisenberg Cut is located between the Meter and the Registrar.

Computer as Observer

Computer-controlled Experiment on LHC



Quantum

Mathematics for description of Quantum

- The number of degrees of freedom $N^{\{Q\}}$ of the Quantum is small; this enables calibration for the instruments that measure non-degenerate observables.
- The Hilbert space $H = C^{N^{\{Q\}}}$ contains a subspace of normalized pure-state vectors $V_{pure}^{\{Q\}} \sim S_{2N^{\{Q\}}-2}$.
- Algebra of observables $A^{\{Q\}} \sim R^{N^{\{Q\}}}$.
- Special unitary group $SU(N^{\{Q\}})$.
- Space of density matrices of mixed states $V_{mix}^{\{Q\}} \sim SU(N^{\{Q\}}) \times T_{N^{\{Q\}}} \subset R^{N^{\{Q\}^2-1}$ (T_N is simplex in R^N).

Observable to be measured

$$A = \sum_{m=1}^{N^{\{Q\}}} A_m \Pi_m; \quad \sum_{m=1}^{N^{\{Q\}}} \Pi_m = \hat{I}; \quad \Pi_m = |m; A\rangle \langle m; A| \quad (1)$$

Probability

Rigorous Definition

Random variable is the probability triple $(\Omega, \mathbb{P}, \sigma(\Omega))$

- The sample space Ω by Eq. (1):

$$\Omega = \left\{ \omega_m \equiv (|out\rangle = |m; A\rangle), m = 1, \dots, N^{\{A\}} \right\}. \quad (2)$$

- The space of all events must be a σ -algebra on Ω .
- Probability distribution $\mathbb{P} = [P_1, \dots, P_{N^{\{A\}}}]$ is defined by measured state $|in\rangle$ and outcome state $|m; A\rangle$ in accordance with Born rule $P[\psi; res] = |\langle res | \psi \rangle|^2$:

$$\mathbb{P}[A] = \left\{ P_m = |\langle m; A | in \rangle|^2, m \in 1, N^{\{A\}} \right\}. \quad (3)$$

Superposition of Schrodinger Cat states

The superposition of the live and dead Cat states is not present in the sample space $\Omega = \{|live\rangle, |dead\rangle\}$; therefore, no trial of a random variable can give a statement regarding this superposition.

Dynamics of Meter with Quantum

Non-stationarity

$$U(t) = e^{-iH^{\{MQ\}}t}, \quad \rho^{\{MQ\}}(t) = U(t) \rho_m^{\{M\}} \times |in; Q\rangle \langle in; Q| U^\dagger(t) \quad (8)$$

Stationary States of Meter with Quantum

$$H_m^{\{M\}} = \sum_{n=1}^{N^{\{M\}}} E_{n,m} |n; m, Q\rangle \langle n; m, Q|, \quad \rho_m^{\{MQ\}} = F(H_m^{\{M\}}) \times |m; A\rangle \langle m; A|. \quad (9)$$

$$F(\cdot) : R^{N^{\{M\}}} \mapsto T_{N^{\{M\}}}, \quad T_K \text{ is a simplex in } R^K.$$

Heisenberg Cut

Measurement of the Meter

Determination of distance from density matrix to a subspace is performed through a large number of measurement series for incompatible observables with appropriate processing of the results obtained. There is no state of the "Meter and Registrar" system in which this distance takes a discrete value; the process of determination of this distance is not a quantum measurement and is to be considered as a classical measurement.