A Question for Penrose's OR and Orch-OR

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Motivation

Roger Penroses's proposal for objective reduction of superpositions of masses is motivated from a clash between the quantum superposition principle and principle of general covariance, and assuming supremacy of the latter principle.

Penrose's proposal is also one of the lynchpins of Orchestrated Objective Reduction (Orch-OR), developed with Stuart Hameroff.

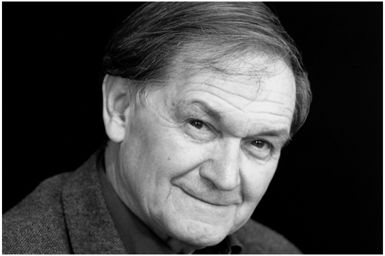
There is a crucial aspect of Penrose's proposal, hence also Orch-OR, that seems to me a serious (and possibly fatal) problem for it.

To keep an open mind, I will pose it as a question for defenders of Penrose's proposal and Orch-OR.

Penrose Argument 1

RP (1996): Conventional assumptions about quantizing Einstein gravity lead to a fundamental inconsistency for superpositions of masses and the spacetimes they live in.

Inconsistency follows from clash between quantum superposition principle and principle of general covariance. Can't have both!



Penrose Argument 2

RP's example: In standard quantum theory, a lump of mass in a flat background spacetime can be prepared in one of two orthogonal stationary states $|\psi_1\rangle$ and $|\psi_2\rangle$ of the Hamiltonian operator $\hat{H}$ such that

$$i\hbar\partial_t |\psi_1\rangle = E |\psi_1\rangle , \quad i\hbar\partial_t |\psi_2\rangle = E |\psi_2\rangle , \tag{1}$$

The lump of mass can also be prepared in the cat state

$$|\Psi\rangle = c_1 |\psi_1\rangle + c_2 |\psi_2\rangle \tag{2}$$

which is also a stationary state satisfying

$$i\hbar\partial_t |\Psi\rangle = E |\Psi\rangle . \tag{3}$$

Penrose Argument 3

For a quantum state $\psi(\mathbf{x}, t)$ to be stationary, its associated background spacetime must also be stationary.

In GR, stationarity of a spacetime defined as presence of timelike Killing vector $\boldsymbol{\kappa}$ ($\boldsymbol{\kappa} = \partial_t$ only in flat spacetimes).

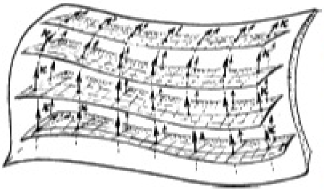


Fig. 30.3 Stationarity of a spacetime is expressed as the presence of a timelike Killing vector $\boldsymbol{\kappa}$. This generates a continuous family of time-displacements preserving the metric. If $\boldsymbol{\kappa} = \partial/\partial t$, where t is the 'time parameter' of a coordinate system (t, x, y, z), then x, y, and z must be constant along the integral curves of $\boldsymbol{\kappa}$. (See §14.7.)

(Reprinted from The Road To Reality by Roger Penrose.)

Penrose Argument 4

So if $|\psi_1\rangle$ and $|\psi_2\rangle$ are associated to a common curved stationary background spacetime with Killing vector $\boldsymbol{\kappa}$, it plays role of generalized time-displacement operator:

$$i\hbar\boldsymbol{\kappa}\,|\psi_1\rangle = E\,|\psi_1\rangle\,, \quad i\hbar\boldsymbol{\kappa}\,|\psi_2\rangle = E\,|\psi_2\rangle\,. \tag{4}$$

Likewise the cat state $|\Psi\rangle$, formed from linearly superposing $|\psi_1\rangle$ and $|\psi_2\rangle$, satisfies

$$i\hbar\boldsymbol{\kappa}\,|\Psi\rangle = E\,|\Psi\rangle\,. \tag{5}$$

All straightforward so far.

Penrose Argument 5

Now let's incorporate the stationary metric tensor fields associated with each stationary state of the lump.

According to RP, conventional viewpoint is that the correct quantum gravity theory (whatever it turns out to be) would admit quantum states of the form $|\psi_i\rangle\,|g_{\psi_i}\rangle$.

Here $|g_{\psi_i}\rangle$ is the quantum state of an approximately classical metric tensor field corresponding to the stationary state $|\psi_i\rangle$ of the lump.

IOW, the state $|g_{\psi_i}\rangle$ corresponds to an approximately stationary, approximately classical spacetime with Killing vector $\boldsymbol{\kappa}_{\psi_i}$ where

$$i\hbar\boldsymbol{\kappa}_{\psi_1}\,|\psi_1\rangle = E\,|\psi_1\rangle\,, \quad i\hbar\boldsymbol{\kappa}_{\psi_2}\,|\psi_2\rangle = E\,|\psi_2\rangle\,. \tag{6}$$

Penrose Argument 6

But now we run into a problem if we try to make a superposition (gravcat) state:

$$\left|\widetilde{\Psi}\right\rangle := c_1 \left|\psi_1\right\rangle \left|g_{\psi_1}\right\rangle + c_2 \left|\psi_2\right\rangle \left|g_{\psi_2}\right\rangle . \tag{7}$$

What would be the Killing field for $\left|\widetilde{\Psi}\right\rangle$?

Killing vectors $\boldsymbol{\kappa}_{\psi_1}$ and $\boldsymbol{\kappa}_{\psi_2}$ cannot be identified with each other because they are vector fields on different spacetimes!

If we try to think of these two spacetimes as actually being the same space but with slightly different metric tensor fields, g_{ψ_1} and g_{ψ_2}, contradicts principle of general covariance.

That is, we'd have to specify a pointwise identification between the two spacetimes, but general covariance says there should be no preferred pointwise specification between two different spacetimes (would entail a preferred coordinate system).

Penrose Argument 7

So we have a fundamental inconsistency between quantum superposition principle and principle of general covariance.

And the inconsistency persists even in non-relativistic regime.

Two possible conclusions to draw:

1. *Reject* general covariance as fundamental principle of quantum gravity theory.
2. *Reject* quantum superposition principle as fundamental principle.

Penrose Argument 8

<u>**Rejecting general covariance**</u>:

Just say that g_{ψ_1} and g_{ψ_2}, are slightly different metric tensor fields on the same space, hence can identify $\boldsymbol{\kappa}_{\psi_1}$ and $\boldsymbol{\kappa}_{\psi_2}$.

Standard quantum theory with Newtonian gravity violates general covariance: same $\partial/\partial t$ for each stationary component of superposition.

So does General Relativity in Hamiltonian picture with 'reduced phase space quantization'; violates general covariance because picks preferred 3-dimensional background structure or 'gauge' (Anastopoulos & Hu, 2013).

Penrose Argument 9

Rejecting quantum superposition principle:

RP's proposal to "gravitize quantum theory" rejects universal validity of quantum superposition principle to space-time:

So far no concrete proposal for fully relativistic quantum gravity level, but non-relativistic proposal has been described (RP, 1996).

Penrose's OR

1) Assume existence of non-relativistic version of the superposition

$$\left|\widetilde{\Psi}\right\rangle := c_1 \left|\psi_1\right\rangle \left|g_{\psi_1}\right\rangle + c_2 \left|\psi_2\right\rangle \left|g_{\psi_2}\right\rangle . \tag{8}$$

2) Posit that it remains stable for *average* time $\tau \approx \hbar/E_G$, where E_G is *gravitational self-energy* of the *difference* between the two stationary mass distributions at the two (identified) locations in the two respective spacetimes.

$$E_G = \int (F_1 - F_2)^2 \, d^3x = \int (\nabla\Phi_1 - \nabla\Phi_2) \, d^3x \tag{9}$$

Measure of "incompatibility" between two spacetimes at some (identified) instant of time.

3) Superposition reduces to one of the alternatives in τ.

Question for Penrose's OR

Penrose's approach, based on "gravitizing" QM, assumes the quantum-gravitational superposition of stationary states already exists.

As we've seen, this kind of superposition has *no* corresponding time-displacement operator—it doesn't statisfy a Schroedinger equation.

But then how could such a superposition 'dynamically develop' in the first place?

We know it's possible to prepare a body of mass M (neutron, electron, macromolecule, nanosphere, etc.) into a superposition of stationary states corresponding to two different COM locations in 3-space, where the superposition size is (much) larger than the initial wavepacket width of the mass (the initial wavepacket also being a superposition of stationary states). This is done experimentally all the time.

It appears that Penrose's approach, which insists on preserving the principle of general covariance, cannot describe this experimental fact.

Question for Orch-OR

In Orch-OR, microtubules are supposed to dynamically develop into a superposition of stationary states, stay that way for avg time τ, reduce, then dynamically develop into such superpositions again.

Moreover a mechanism is suggested by Penrose and Hameroff for how dynamical development of the superpositions could happen (2014):

"The only tubulin conformational factor required in Orch OR is superposition separation at the level of atomic nuclei, e.g. 2.5 Fermi length for carbon nuclei (2.5 femtometers; 2.5 $\times 10\hat{}-15$ meters). This shift may be accounted for by electronic cloud dipoles with Mossbauer nuclear recoil and charge effects [90,91]", p. 68.

But dynamical re-development of the superposition after reduction, by this or some other mechanism, cannot happen if there's no time-displacement operator for the superpositions to develop w.r.t.

How then are microtubules supposed to (re)develop into superpositions of different curved spacetimes in the brain?

Easy Answer

Reject general covariance: think of g_{ψ_1} and g_{ψ_2}, as slightly different metric tensor fields on the same space, hence can identify $\boldsymbol{\kappa}_{\psi_1}$ and $\boldsymbol{\kappa}_{\psi_2}$.

Penrose wouldn't like this, but what's the alternative that preserves the principle of general covariance?

Thanks To

- Catalina, and you the audience!
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