Time travel in Timeless Universes

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Motivation

* Merging the "block universe" of relativity with the quantum dynamics

* Reconciling relativistic causality with the uncertainty principle

Quantum Gravity?

Page - Wootters

Dynamics without dynamics

$$(H_C + H_R)\,|\Psi\rangle_{CR} = 0$$

$$|\Psi_{CR}\rangle = \sum_n |\psi_C^n\rangle\,|\beta_R^n\rangle$$

($|\psi_C^n\rangle$: geometry; $|\beta_R^n\rangle$: fields)

$$|\psi_C^m\rangle \to |\psi_C^{m+1}\rangle$$

$$e^{-iH_R\tau}\,|\psi_R^m\rangle = |\psi_R^{m+1}\rangle$$

Backward in time?

$$|\psi^c_{100}\rangle \to |\psi^c_{99}\rangle$$

$$|\phi^R_{100}\rangle \to |\phi^R_{99}\rangle$$

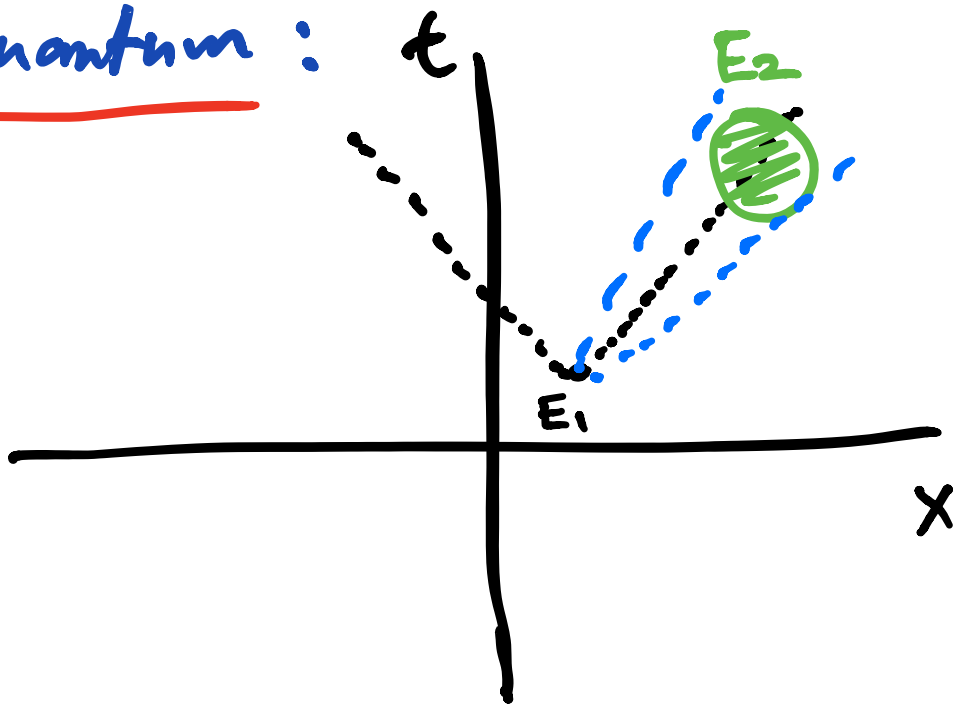
but ϕ_n contain "memory" of "times" only up to n.

$\therefore$ no inconsistency!

Quantum Causality

Relativity: two events either spacelike, timelike or null.

Quantum:

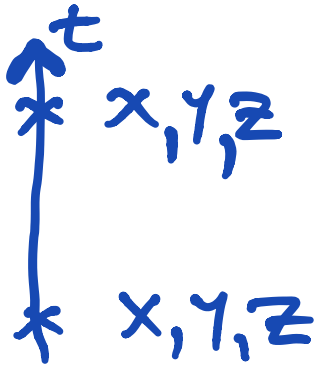


But wavefunction encodes information about simultaneous events and is then evolved in time.

Why not encode quantum states into the same object irrespective of whether they reflect space like or time like correlations?

Pseudo-density Matrix

e.g. $\rho = \frac{I}{2}$



Different times are assigned different Hilbert Spaces.

$$R_{12} = \frac{1}{4}(I \otimes I + X \otimes X + Y \otimes Y + Z \otimes Z)$$

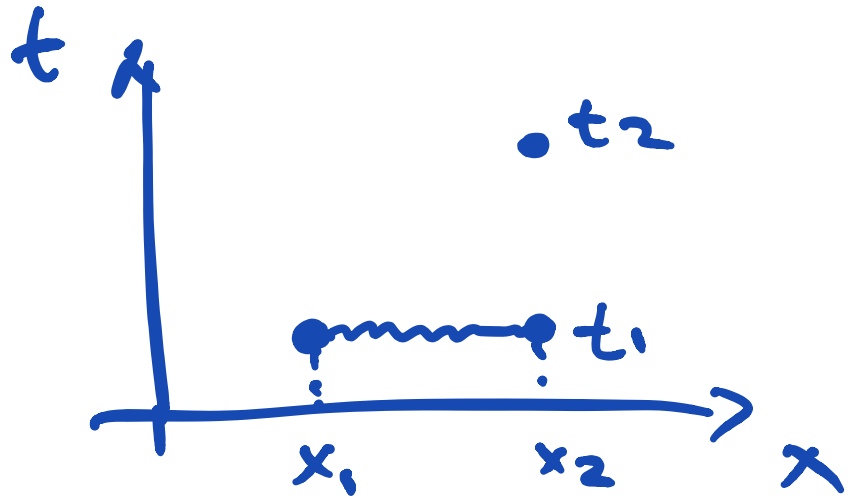
n.b. not a physical state

Anti-singlet and anti-triplet

	XX	YY	ZZ
R^1	+1	+1	+1
R^2	+1	−1	−1
R^3	−1	+1	−1
R^4	−1	−1	+1

Maximally entangled temporal states are partial transposes of the Bell states.

Can combine space and time



3-qubit pseudo density

$$R_{123} = \frac{1}{8}\Big(I - X_1\otimes X_2 - Y_1\otimes Y_2 - Z_1\otimes Z_2 + X_2\otimes X_3 + Y_2\otimes Y_3 + Z_2\otimes Z_3 + X_1\otimes X_3 + Y_1\otimes Y_3 + Z_1\otimes Z_3 - X_1\otimes X_2\otimes X_3 - Y_1\otimes Y_2\otimes Y_3 - Z_1\otimes Z_2\otimes Z_3\Big)$$

Tracing out works just as well

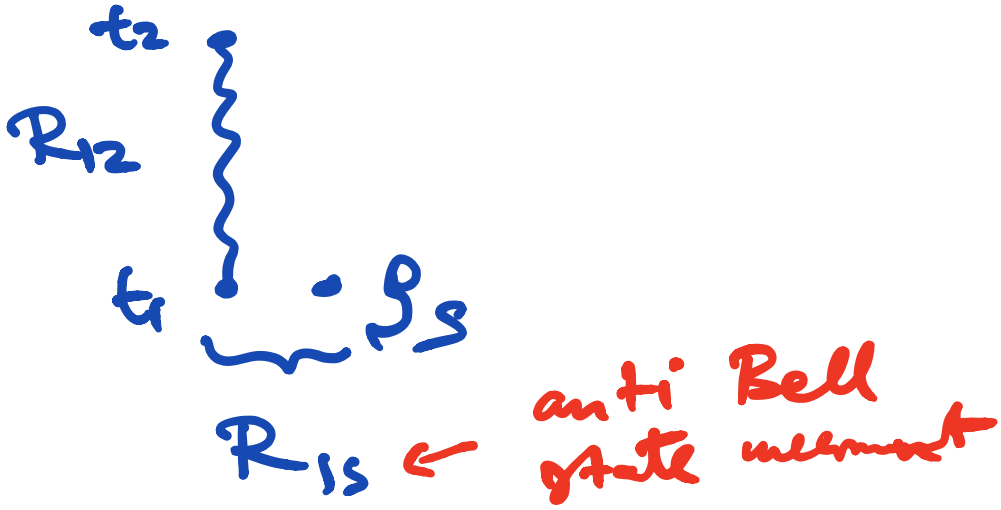
$$\langle A_2 \rangle = \mathrm{tr}_{123}(I \otimes A_2 \otimes I) R_{123}$$

$$= \mathrm{tr} A_2 \cdot R_2$$

where $R_2 = \mathrm{tr}_{13} R_{123}$.

Generalizes to any number of spacetime points + any dimensionality of systems.

Dynamics & Temporal Teleportation



$\rho \to \mathcal{T}(\rho)$ as teleportation.

$$\rho_2 = 4\,\mathrm{Tr}_{1S}\left(\rho_S \otimes R_{12}\right) \cdot R_{1S}$$

e.g. $\frac{1}{2}(I + r_x x + r_y y + r_z z)$

$\rightarrow \frac{1}{2}(I + \eta_x r_x x + \eta_y r_y y + \eta_z r_z z)$

need

$$R_{12} = \frac{1}{4}(I + \eta_x x x + \eta_y y y + \eta_z z z)$$

n.b. analogy with Lorentz

$$\begin{pmatrix} t+z & x+iy \\ x-iy & t-z \end{pmatrix} \rightarrow \begin{pmatrix} t'+z' & x'+iy' \\ x'-iy' & t'-z' \end{pmatrix}$$

Bohm → Penrose → Weizsäcker

→ Wheeler

Lorentz transformations are analogous to teleportation in time.

How much of quantum physics is just relativity?

Age Bohr → fortnightness.

Back in time evolution can be phrased as teleportation from t_2 to t_1, using R_{12}.

But what does that mean?

Even more ...

Pseudo-densities are developed in non-relativistic quantum mechanics.

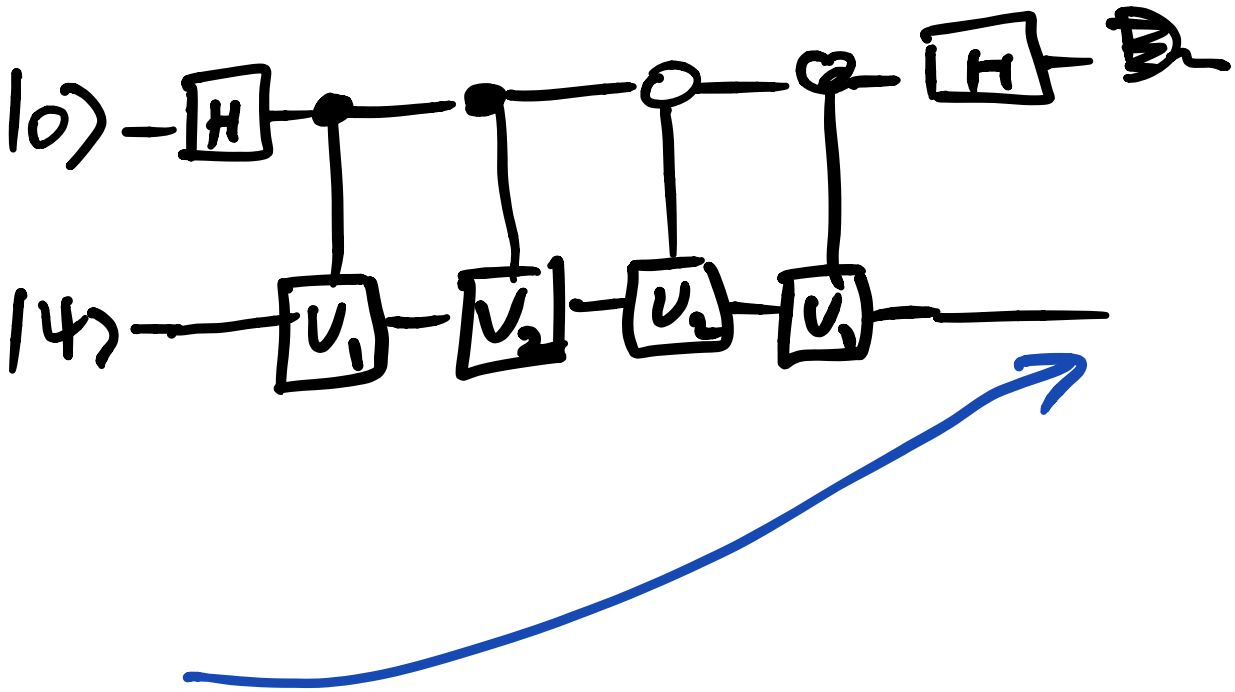
They need to be "relativised" but relativity also needs to be quantized!

Superposition of causal orders?

$$(U_2 U_1 + U_1 U_2)|\psi\rangle$$

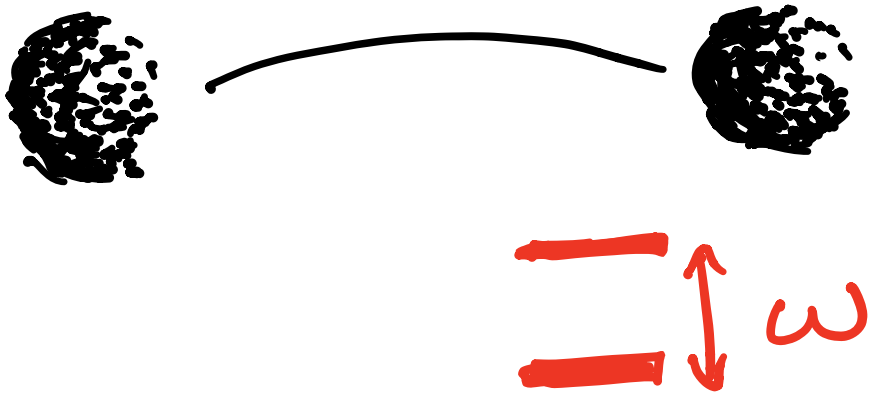
Could this reflect some underlying superposition of different spacetimes?

Quantum Switch



$$(U_1 U_2 \pm U_2 U_1)\,|\psi\rangle$$

Massive superposition?



$$(|x_1\rangle + |x_2\rangle)(|0\rangle + |1\rangle)$$

$$\rightarrow |x_1\rangle\left(|0\rangle + e^{i\omega t_1}|1\rangle\right) +$$

$$|x_2\rangle\left(|0\rangle + e^{i\omega t_2}|1\rangle\right)$$

All this could be described both in Page-Wootters and with Pseudo-densities.

But can all orders be superposed?

cf. Oreshkov + Vedral

Relativistic Chronology

Robb 1914

Given n space like events can we always find inertial frames in which observers perceive them in any chronological order?

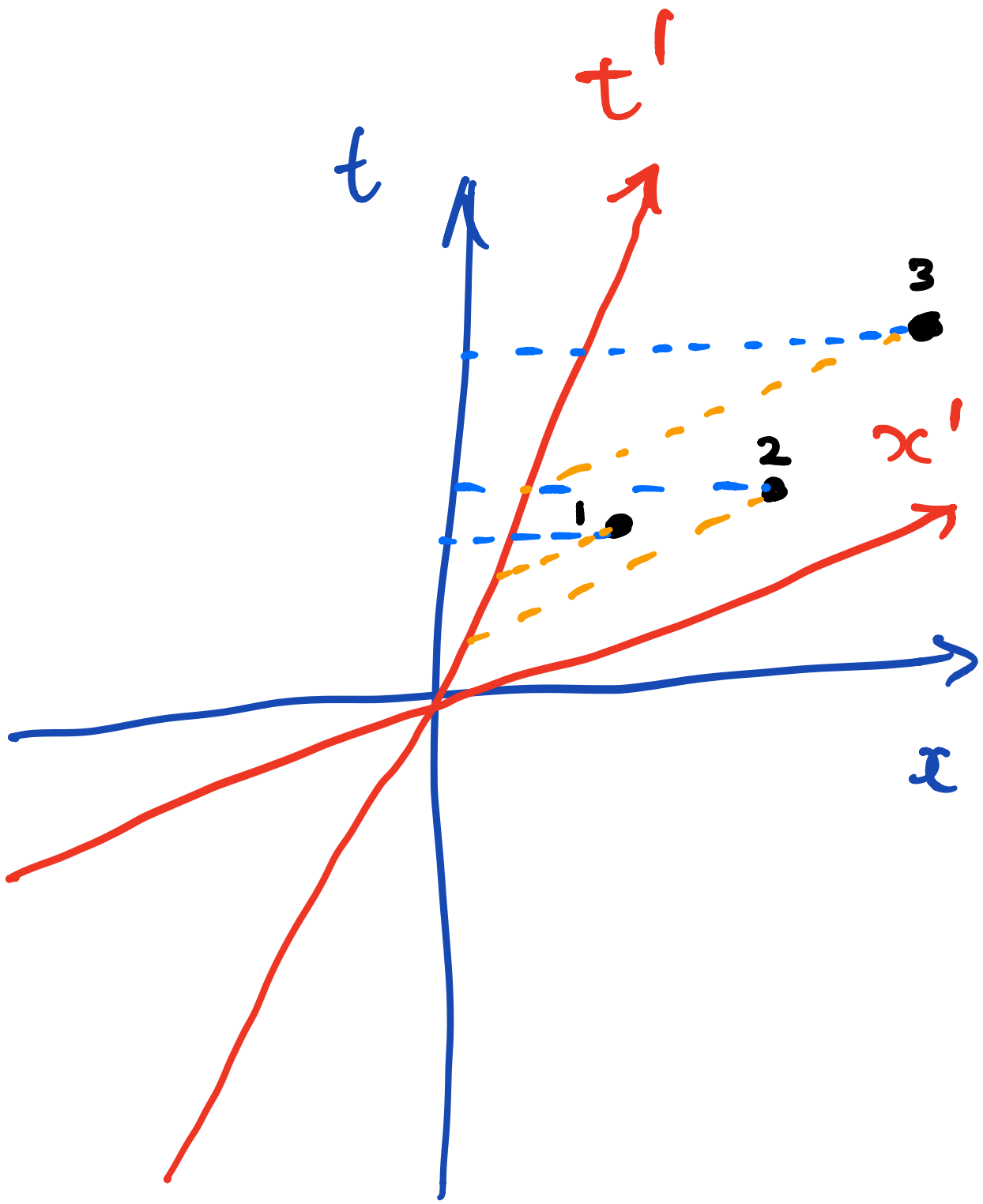
No!

E.g 1+1 dimensions

$(1,2,3), (2\,3\,1), (3\,1\,2)$

is a disallowed set of permutations.

or one of the observers would have to travel faster than light!


t'
t
3
2
1
x'
x

Quantum Chronology

$$|(1,2,3)\rangle + |(3,1,2)\rangle + |(2,3,1)\rangle$$

Should this be disallowed? OR

$$|Q_1\rangle|P_1\rangle + |Q_2\rangle|P_2\rangle + |Q_3\rangle|P_3\rangle$$

be disallowed?

GR only makes it more complicated

...

Still outstanding how to combine:

*) locality (general, c.f. Chiara)
*) unitarity (quantum)
*) causality (special rel.)
*) equivalence (gen. rel.)