Relativistic theories of quantum mechanics

What do we want from Galilean theories?

- Laws to hold in all Galilean frames
- Galilean transformations “commute” with the laws of dynamics (it is the same if we apply coordinate transformation first and then the laws of dynamics or the other way around (the operators corresponding to Galileo boosts commute with the Hamiltonian of the system)
- Vacuum has the same functional form in all Galilean systems.

Is Lorentz transformation similar to Galileo transformation?

- Not at all.
- Simultaneity is affected by the Lorentz boost
- Moreover, the dynamical laws are changed because they are “hyperplane dependent”.
- Which is the cause of the change? Lorentz transformation or the change of hyperplane (see Fleming’s theory)

Relativistic Collapse Theories

If there is a **relativistic theory of wave collapse,** then it needs to:

A. Admit/represent the collapse of the wave function
B. Stay relativistic
C. Be a stochastic theory
D. Be local (is this a strong requirement?)

Some options to be discussed here

1. QFT (under the restriction of the ETCR)
2. Delayed collapse
3. Transactional interpretation (+backward causation)
4. Hyperplane dependence indexicality.

Problems:

1 does not meet A

2 is inconsistent with experiment

3 does not meet C

Seemingly there is no theory meeting A-D; for Maudlin, the strongest candidate is D

QFT with no collapse

- We can get the Lorentz invariance for theories that do not have collapse.
- All operators commute at different places or different times. A scalar field ϕ and its momentum π **at t=0** are such that:

$$\left[\phi(x),\pi(x')\right]=i\delta(x-x');\left[\pi(x),\pi(x')\right]=\left[\phi(x),\phi(x')\right]=0$$

- This is against Maudlin's previous results according to which superluminal causation and information is necessary to reproduce quantum statistics.

Delayed collapse

- We can let the collapse propagate along the light cone. This is the "delayed collapse theory". Of course, the delayed collapse comes too late to account for the quantum correlations.

Backward causation and correlations

I [Pais] recall that during one walk Einstein suddenly stopped, turned to me and asked whether I really believed that the moon exists only when I look at it

(A. Pais, 1982).

- I.e. the state of the detectors influence the state of the photons produced
- Cramer's theory or the transactional interpretation of QM
- The absorber sends a message to the emitter backwards in time and the emitter sends a confirmation message to the absorber, "till the transaction is complete"

- Problems (p. 198-199) :
- The collapse happens only in the pseudotime
- Only the completed transaction happens in real time.
- it is nowhere a stochastic theory, but a deterministic theory
- The absorbers need to be passive sitting in the future ready to absorb signals from the emitter. This is too strong a restriction to be plausible

Maudlin contra Cramer (skipped)

Hyperplane dependence (Fleming, 1987)

- A hyperplane is just an geometrical object in SP-T: $\eta^{\mu} x_{\mu} = \tau$ where $\eta^{\mu}\eta_{\mu} = 1$
- Hyperplanes are characherized by the pair (η,τ). Two hyperplanes are parallel when $\eta_1 = \eta_2$
- The position operator becomes: $\eta^{\mu}\hat{x}_{\mu}(\eta,\tau) = \tau$
- The momentum operator of a particle of mass κ is: $\hat{p}^{\mu}(\eta,\tau)\hat{p}_{\mu}(\eta,\tau) = \kappa^2$
- Fleming and Barrett rewrote the whole formalism of QM as indexed to the hyperplane

What is the hyperplane determined by?

I. They are built in the structure of spacetime
II. The state of the motion of the sources
III. The state of the motion of the detectors
IV. The state of the motion of the particles
V. The state of the motion of rest of the Universe

- I is in direct violation of requirement B.
- II and III does not account for the possibility of a concrete dynamics of sources and detectors (they can disappear, they can be moved, changed etc)
- IV usually gives inconsistent choices
- V This is promising, but what if the photon is the only object in the universe?

Subtelties on the hyperplanes

- Each hyperplane has its own time. This is why succesion of events is relative to the hyperplane (see Maudlin 205-206). So
  - succesion/simultaneity
  - Spatial and temporal distances between points in spacetime

are all relative to hyperplanes.

- But can we relativize everything? Some problematic quantities:
  - Polarization
  - Being stochastic/deterministic
- Can these be hyperplane dependent?

What does hyperplane dependence contradict?

- Separability (SEP): each separated region of spacetime has its own intrinsic properties. The only extrinsic relations are spacetime relations. All other relations are determined by the intrinsic properties.
- In Fleming, both separability and locality are relative to a hyperplane.
- SEP is violated because there are no intrinsic properties at all. For example polarization is relative.

Maudlin contra Fleming (1996)

- Hyperplane dependence contradicts locality. “There are non-hyperplane-dependent local beables”
- the wave-function on the hyperplane is “ontologically atomic”

- A question Maudlin does not address: are there GRW-like theories with hyperplane dependence?

Subjectivity and hyperplanes

The hyperplane proponent can reply that we subjectively think that polarization is absolute. In reality we have partial information . Logically speaking, adding indices reduce the possibility of hitting inconsistencies.

By indexicalizing a property to something else we in fact reduce inconsistencies. (point against Maudlin's argument against hyperplane)

What if the distinction stochastic/deterministic is hyperplane-dependent? Or spin, or polarization etc.

What seemingly bothers Maudlin is that some properties which are not dependent on spacetime structures, i.e. polarization or spin, are now relative to hyperplanes.

No-collapse theories and relativity

- Bohm's theory uses simultaneity, so it is blatantly non-relativistic.
- It has no backward causation.
- There was (is?) a hyperplane Bohmian theory. Durr et al (1999) defined a class of Lorentz-invariant Bohmian theory for *N* entangled but *non-interacting* Dirac particles. Somehow Maudlin skim over this option.
- Bohmian disclaimer: the wave-function does not live in a SP-T. IT lives in configuration space.
- But the very notion of "configuration" as used in constructing the configuration space presupposes simultaneity.

Local theories of collapse: many minds

- No determinate results of measurements (assumption 3 in a previous discussion)
- Only individual minds can make a measurement definitive. The detectors, the instruments, the perceptual system are all in indeterminate states
- Only single minds determines a value of the measurement.

Missing link: continuous stochastic localization (Pearle G.R., 1990)

- You start from the purely stochastic GRW called Quantum stochastic model
- Then you postulate a continuous relation between the frames.

Some questions

- I do not get how you can dismiss so easily the QFT/ETCR formalism. It seems that it governs the many mind interpretation too (except the minds).
- I have the impression that Maudlin applies double/triple standards to judge all these variants
- Do we want to eliminate any reference to human observer? Seemingly this is a requirement in discussing Fleming, but not anymore when Many Minds is as stake.
- Advice to Maudlin: when we have to choose our poison, we should look at how the poison work in a bigger context. Look at GR, QFT and other extensions of the theories involved, at least suggest this.
- Does Maudlin adopt a particle chauvinism? We can start from fields as in QFT.
- Is being a mind relative to a frame of reference? Can I be a Albert-Loewer mind in one system and not a single mind in another one?