Introduction to the Ontology of QFT

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The language of standard QFT

- A state of affairs (for all time) is represented by a vector ψ in a space of possible states.
- A physical quantity is represented by an operator $\hat{A}$ on the state space, which takes ψ to another vector $\hat{A}\psi$
- The expected value of $\hat{A}$ in ψ is given by the inner product $(\psi, \hat{A}\psi)$
- Quantities can be localized: $\hat{A}(x, t)$

How to quantize a particle system in QM

- Start with a system characterized by position x and momentum p.
- Treat these as operators, so that $(\psi, \hat{x}\psi)$ is the expected value of x in state ψ.
- Impose commutation relations $[\hat{x}, \hat{p}] = i$ so that the uncertainty principle holds.
- $\hat{x}$ and $\hat{p}$ form a *representation* of these commutation relations (CCRs).
- States now live in the Hilbert space of *superpositions* (combinations) of classical particle states, leading to the measurement problem.

How to quantize a field in QFT

- Start with a classical field $\phi(x, t)$, with "conjugate momentum" $\pi(x, t)$.
- Impose commutation relations on the field and the momentum, $[\hat{\phi}(x, t), \hat{\pi}(x, t)] = i$.
- The field operators $\hat{\phi}(x, t)$ determine the expected value of the field at x, t.
- Observable quantities (energy $\hat{H}$, particle number $\hat{N}$, charges) are operators constructed from the field operators.

Particle interpretations: Definition

Particle number and (perhaps) *position* are among the most fundamental quantities described by QFT.

Arguments against particles

- Usually attack particle number observable $\hat{N}$

Malament: No well-behaved position observable $\hat{x}$.

Halvorson/Clifton: Different observers define different $\hat{N}$, so particle content isn't invariant.

Fraser: $\hat{N}$ does not exist in interacting theories.

Ruetsche: Many curved spacetimes have no $\hat{N}$, or too many.

Rescuing particles?

"Bell type" Bohmian QFT Pilot wave theory with random particle creation/annihilation

- **Q:** What sort of standard QFTs do these require as "input"? Do such QFTs exist?

Non-standard number operators "Off-shell" particles breaking usual mass/energy relationship?

Field interpretations: Definition

The most fundamental quantities described by QFT are properties of spacetime (or entities continuously filling spacetime).

Varieties of field interpretation

Wavefunctional interpretation: States are superpositions of classical fields.

Bohm-type field theories: Pilot wave with field beables.

Spacetime State Realism: Fundamental quantity in region R is the state restricted to R.

Heisenberg Realism: Fundamental quantities in R are observable operators localized in R.

The Hard Problem for field interpretations

Providing a non-stipulative (non-brute) explanation for the connection between states and their detectable predictions.

- State Realism and Heisenberg Realism give us expectation values–what do these mean?
- We don't want "correspondence rules" among the fundamental laws of nature!
- I stand with the Primitive Ontologists.