An ontological approach to (non)locality

Leonardo Oleynik
Prof. Dr. Renato Moreira Angelo

September 27, 2022

Group: Foundations of Quantum Mechanics

Outline

1. Motivation

2. Nonlocality (NL) in physics

    In Newtonian mechanics

    In quantum mechanics

3. A broader notion of NL within Bohmian mechanics (BM)

4. Conclusions

Motivation

Motivation

Einstein on separability

"Its essential for science that things claim an existence independent of one another."

- For physical systems lying in different parts of space, we must have their properties independently determined;
- Without such a clear separation, one cannot grasp how physical laws can be formulated.

Locality

A physical object is influenced directly only by its immediate surroundings.

- Locality is important for physics: a theory in disagreement with it doesn't permit independent statements concerning subsystems.

The goal

Explore a broader notion of locality in Bohmian mechanics (BM).

Locality makes Alice's life much easier.

Nonlocality (NL) in physics

Nonlocality (NL) in physics: the principle of local action

The principle of local action (LA):

For two remote systems (A and B), externally influencing A has no immediate influence on B;

What is meant by *system* and *influence*?

Newton's locality

LA

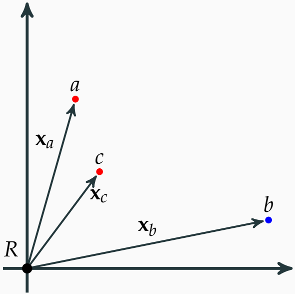
For two remote systems (A and B), externally influencing A has no immediate influence on B.

Newton's ontology:

- *Systems* = particles with trajectories:
- *to influence* = to exert a force;

Newton's locality

Disturbances on A's position cannot instantaneously alter B's acceleration.



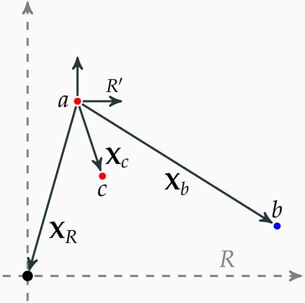
- Laboratory R:

$$m_b \ddot{\mathbf{x}}_b = \mathbf{F}_{ab}(|\mathbf{x}_a - \mathbf{x}_b|) + \mathbf{F}_{cb}(|\mathbf{x}_c - \mathbf{x}_b|).$$

- Let $\mathbf{F}_{ik} =\propto 1/|\mathbf{x}_i - \mathbf{x}_k|^2$ such that disturbances in $\mathbf{x}_i$ will only affect k in a time interval longer than $|\mathbf{x}_i - \mathbf{x}_k|/c$;;
- if $|\mathbf{x}_b| = x_b \to \infty$, then

$$m_b \ddot{\mathbf{x}}_b \approx 0,$$

since $|\mathbf{x}_a - \mathbf{x}_b| \approx x_b \to \infty$ and $|\mathbf{x}_c - \mathbf{x}_b| \approx x_b \to \infty$;



- By employing general covariance to Newton's mechanics, one finds pseudo forces.
- These forces a priori don't need to respect the principle of LA.

Newton's nonlocality

"disturbances on A's position will instantaneously alter B's acceleration".

- R':

$$\mu \ddot{\mathbf{X}}_b = \mathbf{F}_{ab}(X_b) + \frac{m_a}{m_a + m_b}\mathbf{F}_{cb}(|\mathbf{X}_c - \mathbf{X}_b|) + \frac{m_b}{m_a + m_b}\mathbf{F}_{ca}(X_c),$$

where $X_k = |\mathbf{X}_k|$ and $\mu = \frac{m_a m_b}{m_a + m_b}$;

- if $X_b \to \infty$, then

$$m_a \ddot{\mathbf{X}}_b \approx \mathbf{F}_{ca}(X_c),$$

since $X_b \to \infty$, $|\mathbf{X}_b - \mathbf{X}_c| \approx X_b \to \infty$;

Bell's locality

In standard QM, however, the principle is not so easily formulated.

- QM lacks a consensual interpretation of *what a system is*;
- Orthodox interpretation of a quantum system:
  - is fully characterized by the wave function;
  - its evolution is not deterministic (probabilities).

LA

For two remote systems (A and B), externally influencing A has no immediate influence on B.

Bell's locality

A measurement result on B is unaffected by operations on A.

Conclusion:

1. Ontology has a pivotal role in this investigation;
2. Newton's and Bell's notions of locality are incompatible;
3. The best approach toward a unifying notion of locality relies on solid ontological commitments;

Next topic:

A broader notion of NL within Bohmian mechanics (BM)

A broader notion of NL within Bohmian mechanics (BM)

- The universe consists of particles with well-defined trajectories; Generalized state $(\mathbf{x}, \psi)$.
- Two-particle system (a and b): The motion of b is given by

$$m_b \ddot{x}_b = F_b^{[\psi]}(x_a, x_b, t) = -\partial_{x_b}\left(\mathcal{V} + Q^{[\psi]}\right),$$

$$\underbrace{Q^{[\psi]} = -\frac{\hbar^2}{2|\psi|}\left(\frac{\partial^2_{x_a}}{m_a} + \frac{\partial^2_{x_b}}{m_b}\right)|\psi|,}_{\substack{\text{Quantum}\\ \text{potential}}}$$

  if $\psi \neq \psi(x_a)\psi(x_b)$.
- Physical state at t: $\Big(\underbrace{x_a, x_b}_{\substack{\text{System}\\ \text{configuration}}}, \underbrace{\psi}_{\substack{\text{Wave}\\ \text{function}}}\Big)$

A broader characterisation leads to a broader notion of locality

The system's motion can violate the principle of local action for reasons concerning its particle and wave aspects.

- This broader notion encompasses Newton's and Bell's locality into a single framework.

Conclusions

The pivotal role of ontology in the principle of local action (LA)

By assuming Einstein's LA, we noticed the pivotal role of ontology in this investigation:

- Clear ontological statements (system + interaction) $\Rightarrow$ LA formulation;
- Classical system (particle) $\neq$ quantum system (wave) $\Rightarrow$ incompatibles notions of locality;

This leads us to conclude that:

1. *a broader quantum ontology is required.*

Bohmian mechanics is the best candidate for such quantum ontology:

- Both concepts (particle and wave) are required to specify the *system*;
- Broader system's definition $\Rightarrow$ Broader notion of locality.

Thank you!