Is Howard's Separability Principle a sufficient condition for Outcome Independence?

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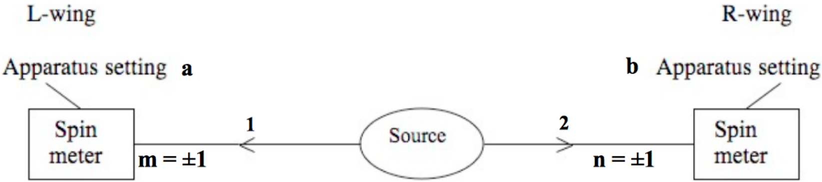
August 10, 2013

Structure

Setting Up



- $p^i_\lambda(m,n|\mathbf{a},\mathbf{b})$: Probability of measuring outcome-pair (m,n) on system(s) i, given joint state λ and parameter settings $\mathbf{a},\mathbf{b}$.

Setting Up

All derivations include factorizability [Jarrett, 1984]

$$p^{12}_{\lambda}(m, n|\mathbf{a}, \mathbf{b}) = p^{1}_{\lambda}(m|\mathbf{a}) \cdot p^{2}_{\lambda}(n|\mathbf{b})$$

Equivalent to conjuct of:

- Parameter Independence (PI)

$$p^{1}_{\lambda}(m|\mathbf{a}, \mathbf{b}) = p^{1}_{\lambda}(m|\mathbf{a})$$
$$p^{2}_{\lambda}(n|\mathbf{a}, \mathbf{b}) = p^{2}_{\lambda}(n|\mathbf{a})$$

- Outcome Independence (OI)

$$p^{1}_{\lambda}(m|\mathbf{a}, \mathbf{b}, n) = p^{1}_{\lambda}(m|\mathbf{a}, \mathbf{b})$$
$$p^{2}_{\lambda}(n|\mathbf{a}, \mathbf{b}, m) = p^{2}_{\lambda}(n|\mathbf{a}, \mathbf{b})$$

How to physically interpret the two?

The argument

- Einstein articulates two principles that let him regard QM as incomplete: Locality and Separability

__LP:__ No supraluminal signalling between space-like separated space-time regions.
__SP__: The contents of any two regions of space-time separated by a non-vanishing spatio-temporal interval constitute separable physical systems, in the sense that each possesses its own, distinct physical state __[SP(1)]__, and the joint state of the two systems is wholly determined by these separate states __[SP(2)]__ __[Howard, 1989, 226]__

- Locality $\leftrightarrow$ PI, Separability $\leftrightarrow$ OI

Formalizing separability

State separability condition [Howard, 1989]

Two systems 1 and 2 are "state separable" if there exist distinct states α and β for these systems s.t.

$$p^{12}_{\lambda}(m, n|\mathbf{a}, \mathbf{b}) = p^{1}_{\alpha}(m|\mathbf{a}, \mathbf{b}) \cdot p^{2}_{\beta}(n|\mathbf{a}, \mathbf{b}) \qquad \text{(SEP)}$$

State: *A conditional probability measure assigning probabilities to outcomes conditional upon the presence of global measurement contexts.* $(\alpha : m \to p_{\alpha}(m|\mathbf{a}, \mathbf{b}), m \in M)$

- Together with identifications

$$p^{1}_{\alpha}(m|\mathbf{a},\mathbf{b}) = p^{1}_{\lambda}(m|\mathbf{a},\mathbf{b}) \qquad \text{(ID I)}$$

$$p^{2}_{\beta}(n|\mathbf{a},\mathbf{b}) = p^{2}_{\lambda}(n|\mathbf{a},\mathbf{b}), \qquad \text{(ID II)}$$

easily proven that $SEP \equiv OI$ $\quad\therefore$ **no OI → no SP.**

Structure

Laudisa [1995]- Unsoundness of the proof

$$p^1_\alpha(m|\mathbf{a},\mathbf{b}) = p^1_\lambda(m|\mathbf{a},\mathbf{b}) \qquad \text{(ID I)}$$

$$p^2_\beta(n|\mathbf{a},\mathbf{b}) = p^2_\lambda(n|\mathbf{a},\mathbf{b}), \qquad \text{(ID II)}$$

- Laudisa [1995] argues that Howard's equivalence proof is unsound, because ID I/II not generally true.
- State component distinction [van Fraassen, 1991]
  - *Value* component: "fully specified by stating which observables have values and what they are"
  - *Dynamic* component: "fully specified by stating how the system will develop if isolated, and how if acted upon in any definite, given fashion"
- Measurement is interaction → outcome probabilities comprised in the dynamic component of a state, may differ between p_α and p_λ.

Rebuttal

$$p^1_\alpha(m|\mathbf{a},\mathbf{b}) = p^1_\lambda(m|\mathbf{a},\mathbf{b}) \tag{ID I}$$

$$p^2_\beta(n|\mathbf{a},\mathbf{b}) = p^2_\lambda(n|\mathbf{a},\mathbf{b}), \tag{ID II}$$

- However, reference to system via SP ($\alpha^i : m \rightarrow p^i_\alpha(m|\mathbf{a},\mathbf{b}), m \,\epsilon\, M$)
- Detectors in different space-time regions → Two *systems* with distinct states α^1 and β^2

Rebuttal

$$p^1_\alpha(m|\mathbf{a},\mathbf{b}) = p^1_\lambda(m|\mathbf{a},\mathbf{b}) \qquad \text{(ID I)}$$

$$p^2_\beta(n|\mathbf{a},\mathbf{b}) = p^2_\lambda(n|\mathbf{a},\mathbf{b}), \qquad \text{(ID II)}$$

- Formally summarised in ID I/II: Probability for measuring an outcome at some space-time region is completely determined by the state of the system in that region.

$$SP \quad \rightarrow \quad (SEP) \quad \rightarrow \quad \rho^{12}_\lambda = \rho^1_\alpha \otimes \rho^2_\beta \quad \overset{tr_2()}{\rightarrow} \quad \rho^1_\lambda = \rho^1_\alpha$$

$\Rightarrow$ By reference to marginal systems ID I/II entailed by (SEP) .

Information "at" margins

"This is because α, by SP, captures exclusively and exhaustively all the information that λ contains about system 1."

- "...one should not understand the transmission of information$_t$ on the model of transporting potatoes." (Timpson, 2006)
- Probability distributions the same, $S(\rho^1_\lambda) = S(\rho^1_\alpha)$ if (SEP) true
- No recourse to information concept equired for argument

Structure

Fine and Winsberg [2003]- The minimalist *non sequitur*

- Disagree with Howard's formalization: SP does not specify how to formally determine the joint state.
- Can produce joint states that satisfy the separability principle *and* violate Bell inequalities.

$F(..)$

1. Given a joint state λ, first identifies *bijectively* "marginal distributions" $p_\lambda(m|\mathbf{a}), p_\lambda(n|\mathbf{b})$ [SP(1)]
2. Finds two-placed function $F(..)$ that completely reproduces the joint state distribution [SP(2)]

Two possible counters

- Expand argument to factorizability?
- Restrict admissible $F(..)$ to include only factorisable $F(..)$?
  - Minimalism: Violation of Bell inequalities is *mathematical* feature of QM due to the inability to define joint probabilities for incompatible observables.
  - Muller and Placek [2001]: Argument against minimalism involving OI- and PI-like assumptions
    - Motivate restriction of mathematical freedom in devising $F(..)$, based on *physical* principles.
    - Nothing done to motivate exclusion of non-factorisable $F(..)$.

Structure

Berkovitz [1998]- Well localized particles

- Howard's equivalence proof "presupposes that particles in Bell-type experiments are well localized during the measurements".
- SP does not imply this $\rightarrow$ OI not entailed by SP.

Being well-localized (WL)

A system A is well localized in space-time iff for any space-time region the question whether A is constituted by the contents (not necessarily completely) of this region has a well-defined answer and this answer is either "yes" or "no".

Counter?

- Is WL required? Yes. "...contents of ...regions of space-time ...constitute physical systems in the sense that each possess ...distinct state."

⇒ Spatiotemporal criterion of distinctness/individuation.

- Can SP be taken to imply WL? No.
- Can we draw same conclusion? Maybe
  - WL treated as given
  - Question about applicability of SP: Can there be *meaningful* outcome-dependence in situations where SP does not apply?
    - Outcome dependent dynamics collapse (CSL) theories (e.g. GRW)?

Structure

Conditions for upholding the argument

- Committed to:
  - States being dynamical states as discussed by van Fraassen.
  - Subscribe to feasibility of Müller and Placek's framework (SOBST) $\Rightarrow$ orthodox QM incomplete
  - Distinctness of states implies their being well localized (spatio-temporal criterion of individuation)
  - Non-feasability of outcome-dependent dynamic collapse theories (GRW, CSL)
- Strong separability principle $\rightarrow$ little gain in knowing its falsehood.

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