Information Causality, the Tsirelson Bound, and the 'Being-Thus' of Things

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What distinguishes QM from CM?

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- No ('PR' systems: Popescu & Rohrlich 1994)
  - $\exists$ conceivable stronger-than-quantum correlations that are non-signalling
- Why don't we see these correlations in nature?

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- ‘implausible accessibility of remote data’ (Pawłowski et al., 2009, ibid.), ‘things like this should not happen’ (Pawłowski & Scarani, 2016, p. 429).

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How to (begin to) motivate information causality?

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- ‘implausible accessibility of remote data’ (Pawłowski et al., 2009, ibid.), ‘things like this should not happen’ (Pawłowski & Scarani, 2016, p. 429).
- Expresses a generalised methodological sense of Einstein separability, suitable for a theory of communication

Outline

- PR-correlations
- Alice and Bob play a guessing game
- Information causality
- Motivating information causality
- Objections and larger questions

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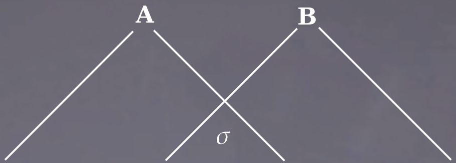

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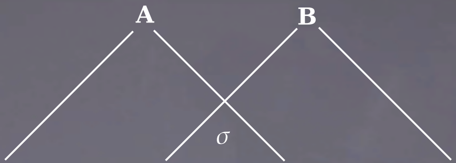

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- a, a', b, b': measurement settings

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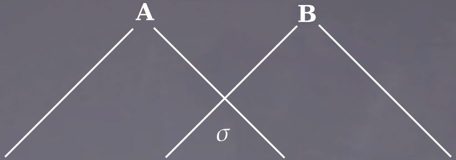

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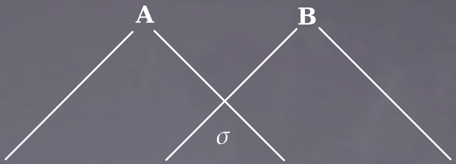

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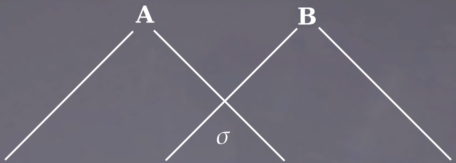

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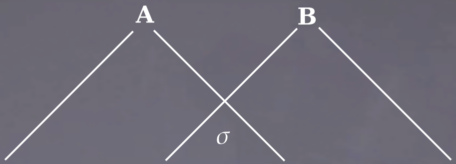

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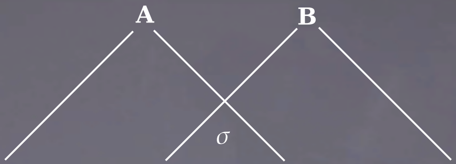

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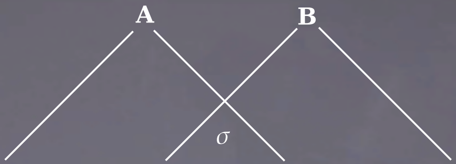

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'Non-signalling': $p(A|a, b) = p(A|a, b')$

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· Pawłowski et al. (2009): 'Information Causality'

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inputs

$$\begin{aligned} a &: 0 \\ a' &: 1 \\ b &: 0 \\ b' &: 1 \end{aligned}$$

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F	T	T
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    - e.g., $\vec{b} = 11 \Rightarrow$ Bob guesses Alice's 3rd bit

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Winning strategy for $N = 2$

Alice and Bob share one PR-system

Alice:

- receives $\vec{a} = a_1 a_0$
- measures $a_0 \oplus a_1$ on her subsystem
- gets result A
- sends $c = a_0 \oplus A$ to Bob

Bob:

- receives $\vec{b} = b_0$
- measures b_0 on his subsystem
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- guesses:
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- sends $c = a_0 \oplus A_I \oplus A_{III}$ to Bob

Bob:

- receives $\vec{b} = b_1 b_0$
- measures b_0 on both box I and box II, $\Rightarrow$ gets B_I and B_{II}
- if $\vec{b} = 00$ or $\vec{b} = 01$,
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Winning strategy for any N

Share $N - 1$ PR-systems:

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What aboout general no-signalling systems?

Recall: probability of successfully simulating a single PR-system:

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In general, probability of a successful answer by Bob in the game (for $N = 2^n$):

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Subtleties:

- not all quantum correlations exceed T.B.
- Evidence that correlations within T.B., but stronger than quantum, satisfy I.C. (Navascués et al., 2015).

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Motivation?

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- How simple is 'too simple'?

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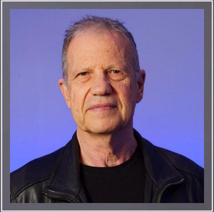

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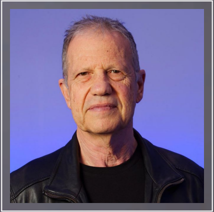

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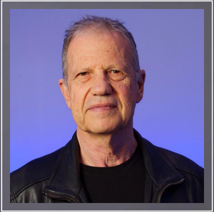

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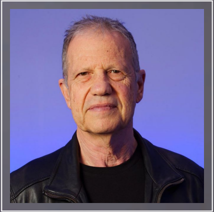

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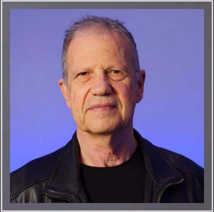

Can a better motivation be given?

Outline

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    - ‘mutually independent existence’

Einstein on Mutually Independent Existence (MIE)

"Without ... an assumption of the mutually independent existence (the 'being-thus') of spatially distant things, an assumption which originates in everyday thought, physical thought in the sense familiar to us would not be possible." (Einstein, translated in Howard 1985, p. 187)

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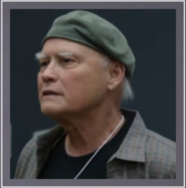
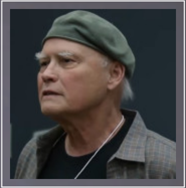
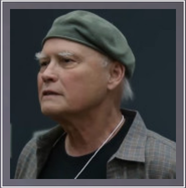
- 'surface-level' constraint (i.e. on the measurable properties of a system)





Demopoulos (In Preparation):

- Mutually Independent Existence (MIE) best thought of as a <u>methodological principle</u> $\Rightarrow$ a constraint on physical practice



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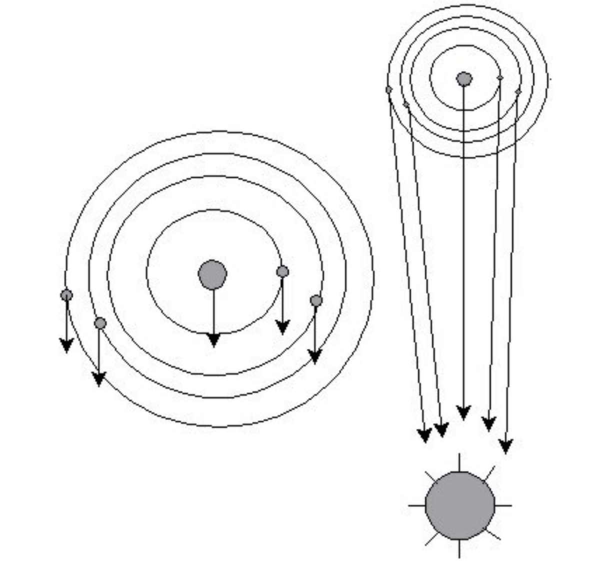

Figure: 1. Source: DiSalle (2016)

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- 'Judo-like manoeuvre': MIE is (in this sense) satisfied in quantum mechanics (no-signalling)

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For $N = 4$, use three PR-boxes: I, II, III

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b_0	a_2	a_3	$a_2 \oplus a_3$	G
0	0	0	0	0
0	0	1	1	0
0	1	0	1	1
0	1	1	0	1
1	0	0	0	0
1	0	1	1	1
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- Does information causality express a form of mutually independent existence?

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    - Non-local joining at the operational level
    - Non-extreme case: Bob has locally accessible information about $\vec{\alpha}$ over and above what's been transmitted to him
    - Extreme case: Alice's bits 'may as well be Bob's' for the purposes of the game:
        - Strategy is just as effective whether Alice's bits are localised with her or with Bob.

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(Quantum) information theory as a ‘practical’ (i.e. resource) theory (MEC 2017; MEC forthcoming)

- in this sense similar to Thermodynamics (Myrvold, 2011; Wallace, 2014; Ladyman, 2018)

Our general approach so far

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- How to make the practice of physics possible

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How to (begin to) motivate information causality:

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How to (begin to) motivate information causality:

- How to make the practice of communicational complexity / information theory, as a ‘practical’ science / resource theory, possible

Bub's gloss on IC: "there can be no information [provided to Bob] about the bits in Alice's data set in the previously established correlations themselves" (Bub, 2012, p. 180)

Failure of IC/MIE:

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Outline

- PR-correlations
- Alice and Bob play a guessing game
- Information causality
- Motivating information causality
- Objections and larger questions

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- One bit of communication needed to win $\Rightarrow$ trivial (communicationally)
- $N - 1 = 2^n - 1$ PR-systems required $\Rightarrow$ exponential / 'hard' (computationally)

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Analogy: Corollary VI

Desirable:

- Show that degree of violation of IC (hence of TB) $\propto$ ‘degree of triviality’

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- not an 'appeal to intuition'
- aim to identify the necessary suppositions implicit in any such theories and in our practice of them
  - what is required for empirical testing to be possible?
  - what distinctions must we make in order to quantify communicational resources?

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    - Distinction between distributed and localised computational tasks becomes 'blurry' / 'confused' for the purposes of a complexity-theoretic analysis if IC is violated.
    - IC as a physically motivated constraint on mutual independence of two mathematical <u>theories</u>

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