Title: Postquantum steering

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URL: http://pirsa.org/16020092

Abstract: <p>The discovery of postquantum nonlocality, i.e. the existence of nonlocal correlations stronger than any quantum correlations but nevertheless consistent with the no-signaling principle, has deepened our understanding of the foundations quantum theory. In this work, we investigate whether the phenomenon of Einstein-Podolsky-Rosen steering, a different form of quantum nonlocality, can also be generalized beyond quantum theory. While postquantum steering does not exist in the bipartite case, we prove its existence in the case of three observers. Importantly, we show that post-quantum steering is a genuinely new phenomenon, fundamentally different from postquantum nonlocality. Our results provide new insight into the nonlocal correlations of multipartite quantum systems.

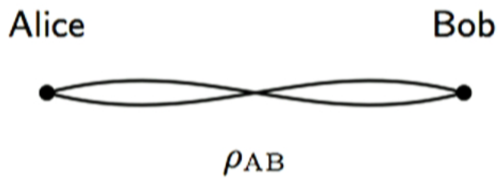
</p>

Postquantum steering

Ana Belén Sainz, Nicolas Brunner, Daniel Cavalcanti
Paul Skrzypczyk and Tamás Vértesi

Phys. Rev. Lett. 115, 190403 (2015)

Entanglement



- Quantum teleportation
- Quantum Key Distribution

Nonlocality

- Device Independent QKD
- Randomness

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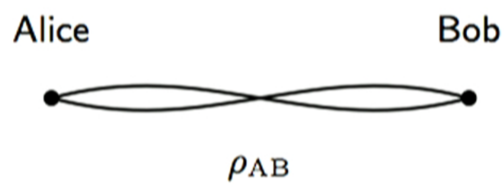

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Steering

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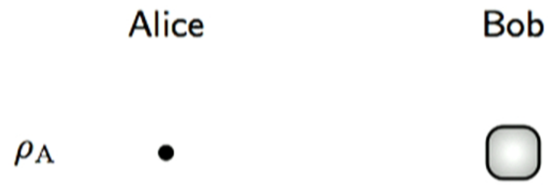
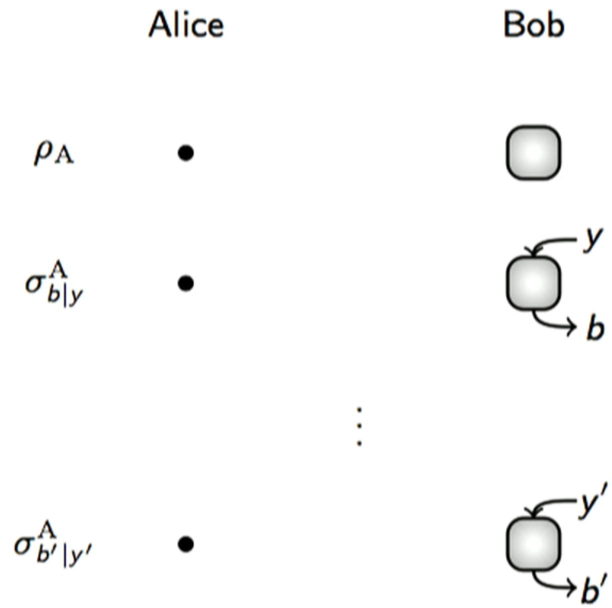


Steering


Alice
Bob
ρ_{A}
$\sigma^{\mathrm{A}}_{b|y}$
y
b
$\sigma^{\mathrm{A}}_{b'|y'}$
y'
b'

Steering

Fix y $\longrightarrow$ ensemble: $\{\sigma^{\mathrm{A}}_{b|y}\}_b$, $\longrightarrow$ $\rho_{\mathrm{A}} = \sum_b \sigma^{\mathrm{A}}_{b|y}$

Assemblage: $\{\sigma^{\mathrm{A}}_{b|y}\}_{b,y}$. $p(b|y) = \mathrm{tr}\left(\sigma^{\mathrm{A}}_{b|y}\right)$.

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Quantum: $\sigma^{\mathrm{A}}_{b|y} = \mathrm{tr_B}\left(\mathbb{1}_{\mathrm{A}} \otimes M_{b|y}\, \rho_{\mathrm{AB}}\right)$

Given an assemblage, **could it have a classical explanation?**

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$\mathrm{tr}\sum_{by} F_{by}\,\sigma^{\mathrm{A}}_{b|y} \leq \beta_{\mathrm{US}}$

Set of "classical" assemblages

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Given an assemblage, **could it have a quantum explanation?**

Bipartite steering

$$\text{Given } \{\sigma^{\mathrm{A}}_{b|y}\}_{b,y}, \quad \rho_{\mathrm{A}} = \sum_b \sigma^{\mathrm{A}}_{b|y}, \quad \mathrm{tr}\,(\rho_{\mathrm{A}}) = 1$$

$$\exists\, \rho_{\mathrm{AB}}, \quad \{M_{b|y}\}_{b,y} \quad \text{st} \quad \sigma^{\mathrm{A}}_{b|y} = \mathrm{tr}_{\mathrm{B}}\left(\mathbb{1}_{\mathrm{A}} \otimes M_{b|y}\, \rho_{\mathrm{AB}}\right)$$

[1] N. Gisin, Helvetica Physica Acta 62, 363 (1989).
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- Alice and Bob: **Yes !** GHJW theorem[1]
- **Multipartite scenarios?**

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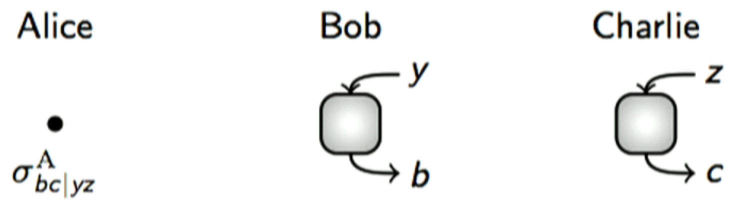
Steering: multipartite scenarios



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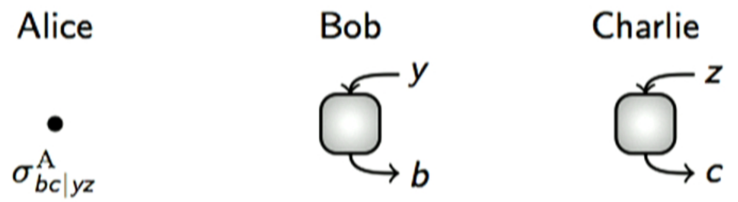

Fix y, z $\longrightarrow$ ensemble: $\{\sigma^{\mathrm{A}}_{bc|yz}\}_{b,c}$, $\longrightarrow$ $\rho_{\mathrm{A}} = \sum_{b,c} \sigma^{\mathrm{A}}_{bc|yz}$

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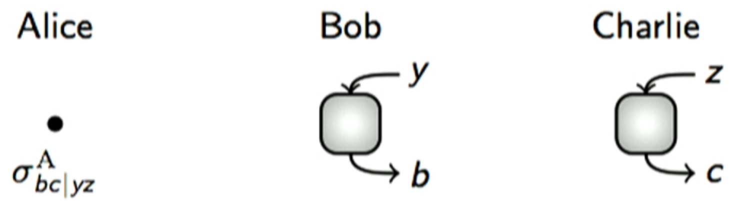

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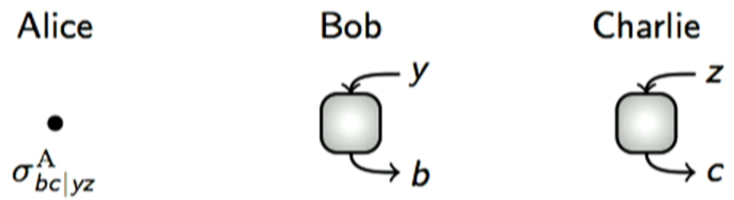

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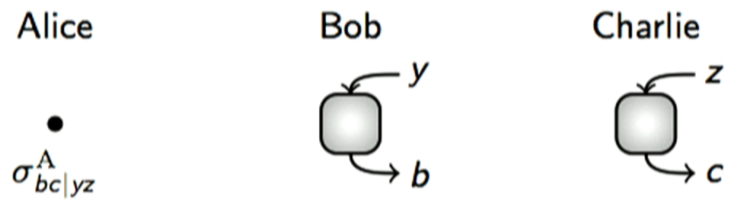

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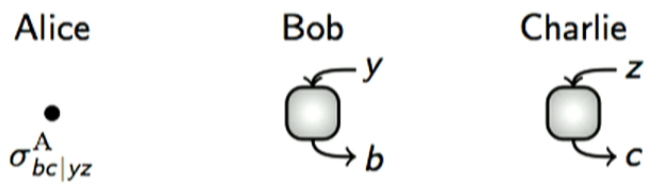
$\exists\, \rho_{\mathrm{ABC}}$, $\{M_{b|y}\}_{b,y}$, $\{M_{c|z}\}_{c,z}$ **st** $\sigma^{\mathrm{A}}_{bc|yz} = \mathrm{tr}_{\mathrm{B}}\left(\mathbb{1}_{\mathrm{A}} \otimes M_{b|y} \otimes M_{c|z}\, \rho_{\mathrm{ABC}}\right)$

Postquantum steering: example



$b, c, y, z \in \{0, 1\}$

$\rho_{\mathrm{A}} = \frac{\mathbb{1}}{2}\,.$

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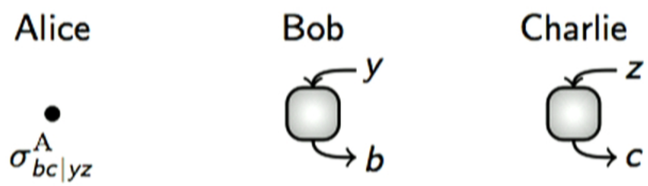

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- $(y, z) = (0, 0)\,, (0, 1)\,, (1, 0)$:

$$\sigma^{\mathrm{A}}_{bc|yz} = \begin{cases} \frac{\mathbb{1}}{4}\,, & \text{if } b = c\,, \\ 0\,, & \text{if } b \neq c\,, \end{cases}$$

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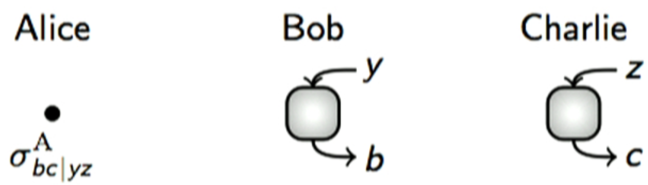

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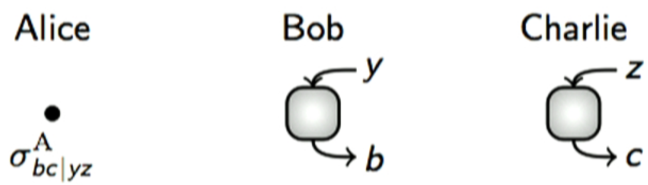

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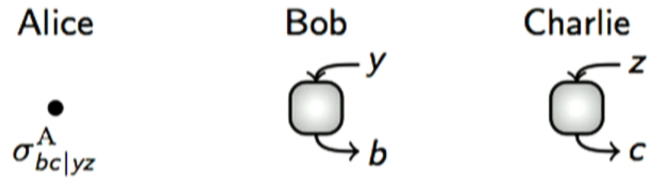
$$p(bc|yz) = \begin{cases} \frac{1}{2}\,, & \text{if } b \oplus c = yz\,, \\ 0\,, & \text{otherwise}\,. \end{cases}$$

No quantum realisation for the assemblage

Postquantum steering: example without postquantum nonlocality



(1) Postquantum assemblage $\left\{\sigma^{\mathrm{A}}_{bc|yz}\right\}_{b,y,c,z}$

(2) Quantum correlations for every measurement by Alice:

$$p(abc|xyz) = \mathrm{tr}\left(M_{a|x} \otimes \sigma^{\mathrm{A}}_{bc|yz}\right)$$

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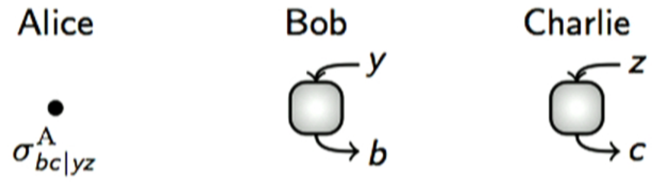

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(1) Postquantum assemblage $\sigma^{\mathrm{A}}_{bc|yz}$

Steering inequality: F_{bcyz}

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How to compute β_{Q}? $\rightarrow$ upper bound

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How to compute β_{Q}? $\rightarrow$ upper bound

Almost quantum assemblages: $\widetilde{\mathrm{Q}} \supset \mathrm{Q}$

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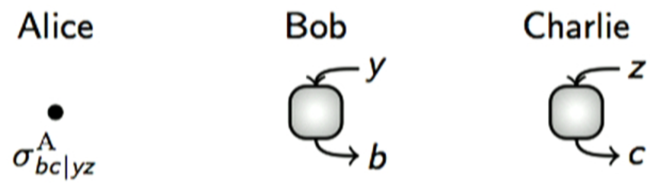
$\mathrm{tr} \sum_{bcyz} F_{bcyz} \, \sigma^{\mathrm{A}}_{bc|yz} > \beta_{\widetilde{\mathrm{Q}}} \quad \Rightarrow \quad \sigma^{\mathrm{A}}_{bc|yz}$ **is postquantum**

Example without postquantum nonlocality



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(2) Quantum correlations $p(abc|xyz)$

(i) $p(abc|xyz)$ is local

(ii) Real qubit assemblage, local for all projective measurements

(iii) Qutrit assemblage, local for all POVMs[2].

[2] F. Hirsch, M. T. Quintino, J. Bowles and N. Brunner, Phys. Rev. Lett, 111, 160402 (2013).

(ii) Qubit assemblage, local for all PVM

$$\Pi_{a|x}(\mu) = \mu\,\Pi_{a|x} + (1-\mu)\,\mathbb{1}/2, \quad \sigma^{\Lambda}_{bc|yz}(\mu) = \mu\,\sigma^{\Lambda}_{bc|yz} + (1-\mu)\,\mathrm{tr}\left(\sigma^{\Lambda}_{bc|yz}\right)\mathbb{1}/2$$

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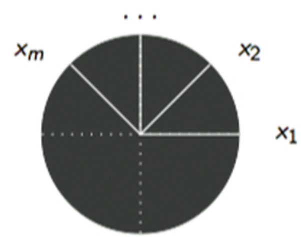

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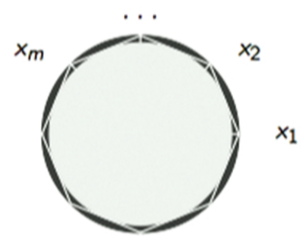

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Postquantum steering: example without postquantum nonlocality

- Four dichotomic measurements (X, Z)
- Search:

Fix $F_{bc|yz}$:

- Compute $\beta_{\tilde{Q}}$ (SDP).
- Find max violation of the inequality by the 'local' assemblages (SDP).
  $\longrightarrow \quad \sigma^{\Lambda}_{bc|yz}$
- Compute $\beta^* = \mathrm{tr} \sum_{bcyz} F_{bcyz}\, \sigma^*_{bc|yz}$, $\sigma^*_{bc|yz} := \sigma^{\Lambda}_{bc|yz}(\mu = \cos(\frac{\pi}{8}))$

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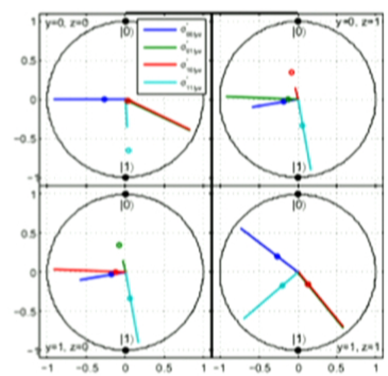

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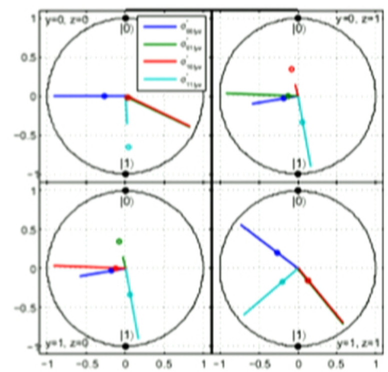

Summary and open questions

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- Genuinely new effect
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- Fundamental difference between bipartite and multipartite scenarios

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Summary and open questions

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- Insight on the characterisation of quantum phenomena
- General framework for non-signalling assemblages
  $\rightarrow$ quantify postquantumness
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Thanks !!!

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