

Genuine Hidden
Quantum
Nonlocality

Marco Túlio
Quintino

Entanglement Vs.
Nonlocality

Local Entangled
States

POVMs...

Hidden
Nonlocality

Genuine Hidden
Nonlocality

Maximal Genuine
Hidden
Nonlocality

Discussions

Genuine Hidden Quantum Nonlocality

Marco Túlio Quintino

Université de Genève

12th August 2013



UNIVERSITÉ
DE GENÈVE

arXiv:1307.4404: F. Hirsch, M.T. Quintino, J. Bowles, N. Brunner

Entanglement Vs. Nonlocality

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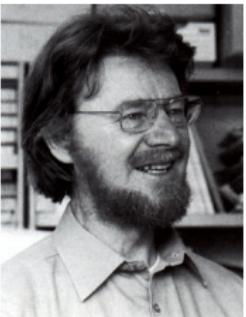
Entanglement Vs. Nonlocality

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Vs.



Entanglement Vs.
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Entanglement

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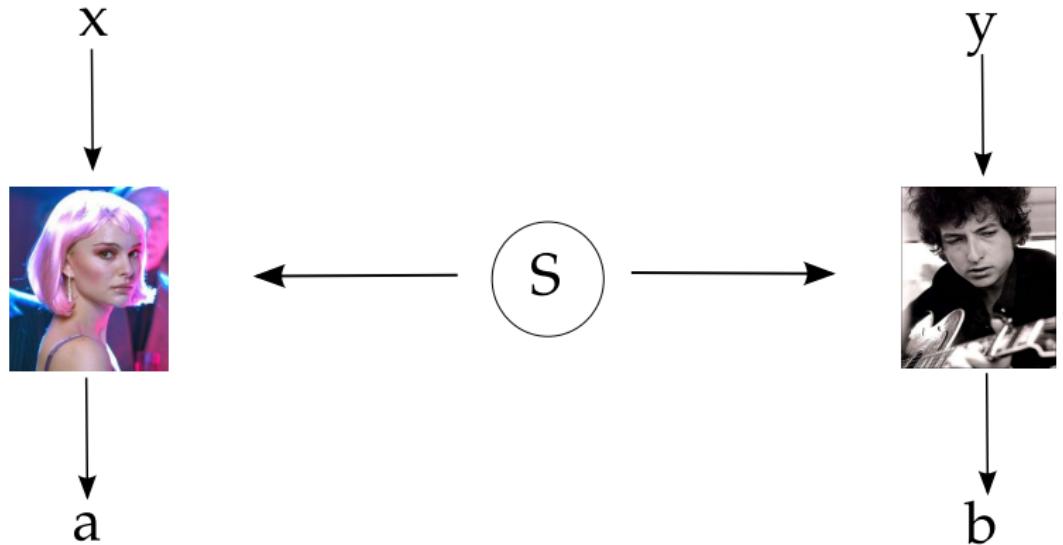
Discussions

$$\rho_{AB} \neq \int \pi(\lambda) \rho_A^\lambda \otimes \rho_B^\lambda d\lambda$$

Bell Scenario

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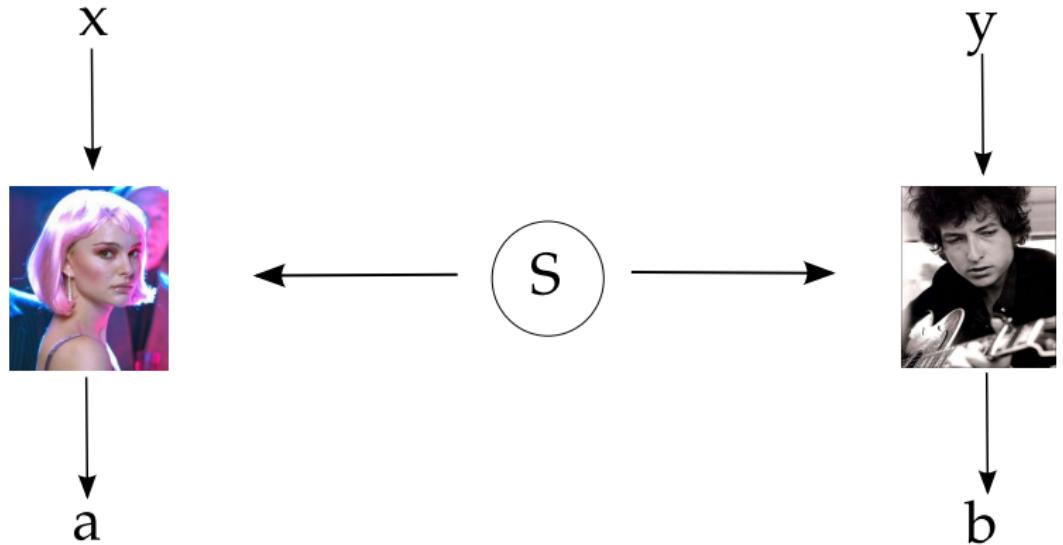
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Bell Scenario



$$p(ab|xy)$$

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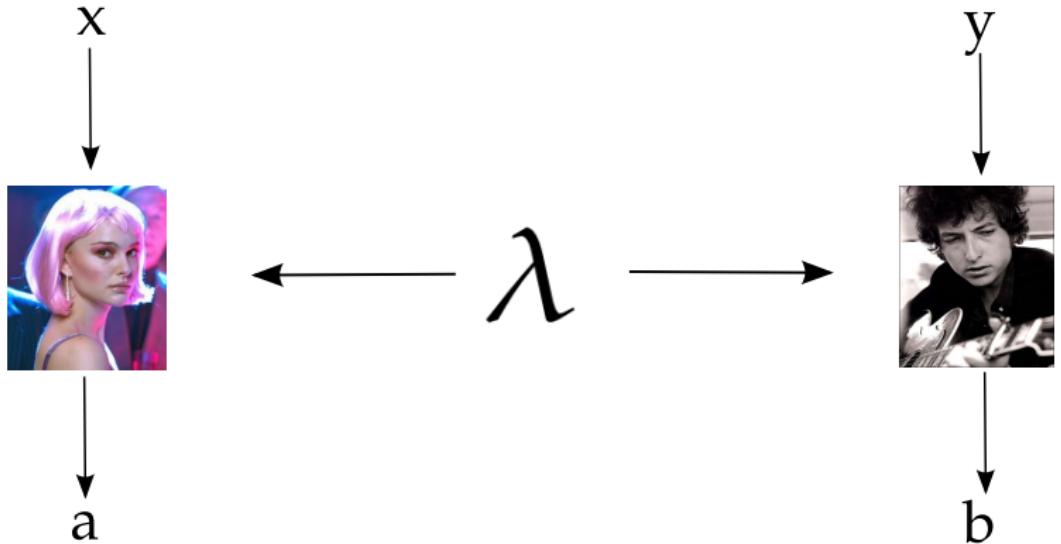
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Locality

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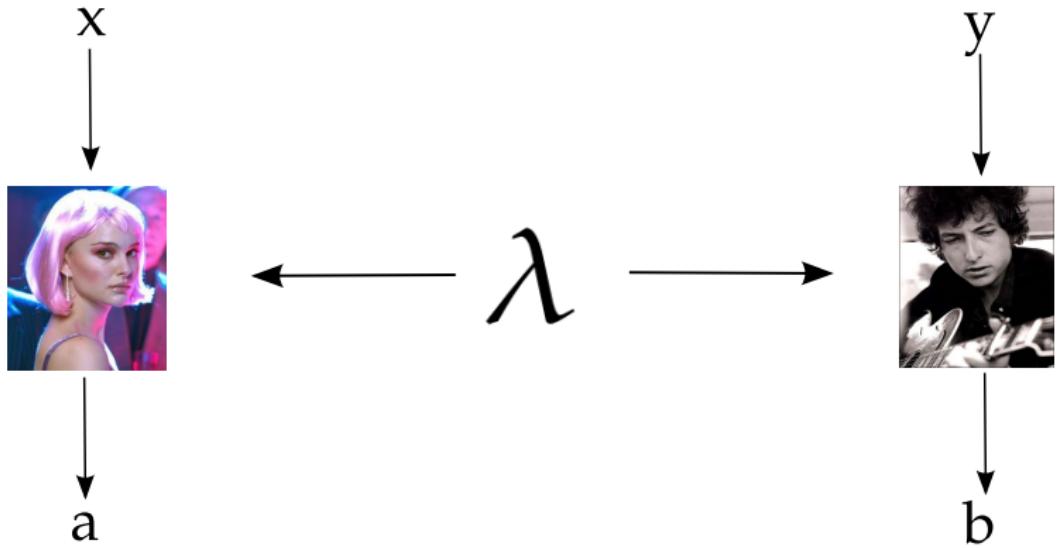
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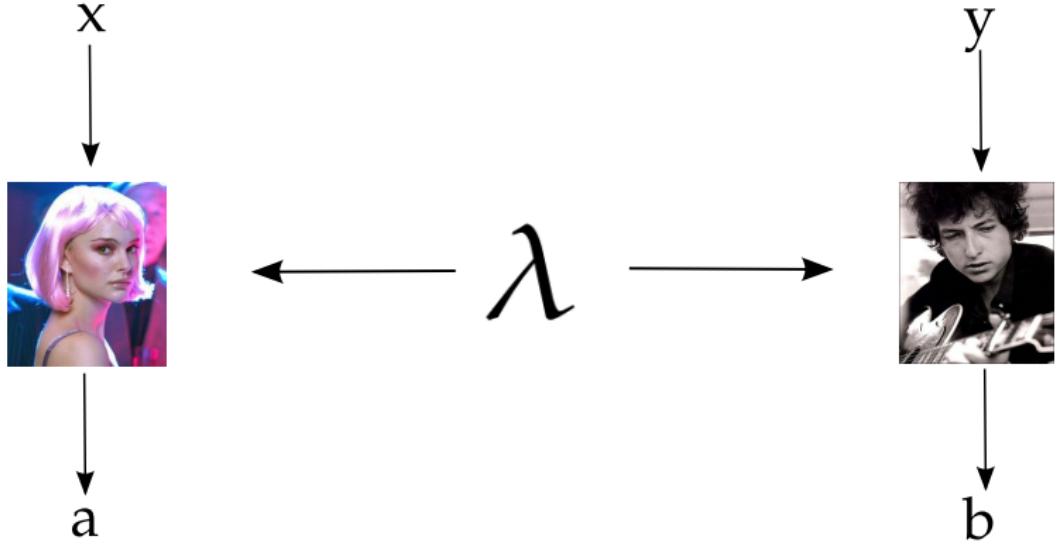
Locality



- ▶ Common cause:

$$p(ab|xy\lambda) = p(a|x\lambda)p(b|y\lambda)$$

Locality



- ▶ Common cause:

$$p(ab|xy\lambda) = p(a|x\lambda)p(b|y\lambda)$$

- ▶ Locality:

$$p(ab|A_xB_y) = \int \pi(\lambda) p(a|x\lambda)p(b|y\lambda) d\lambda$$

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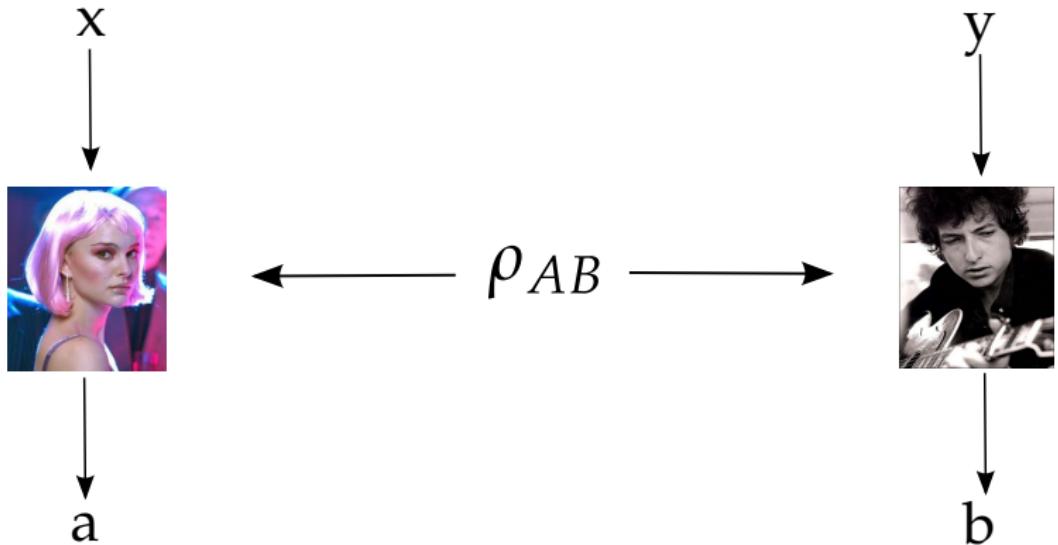
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Quantum Experiments

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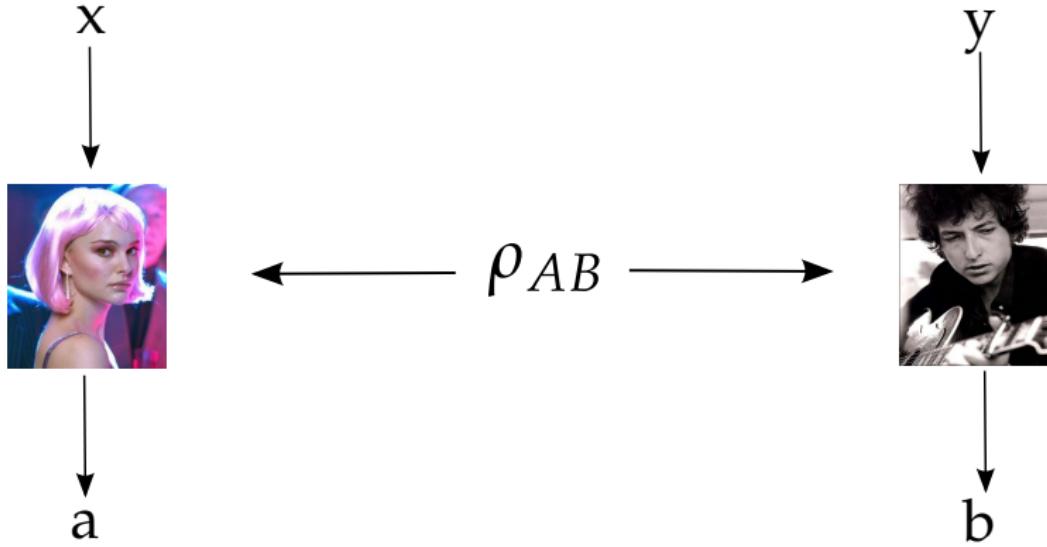
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Quantum Experiments



- ▶ Quantum probabilities:

$$p(ab|xy) = \text{tr} (\rho_{AB} A_a^x \otimes B_b^y)$$

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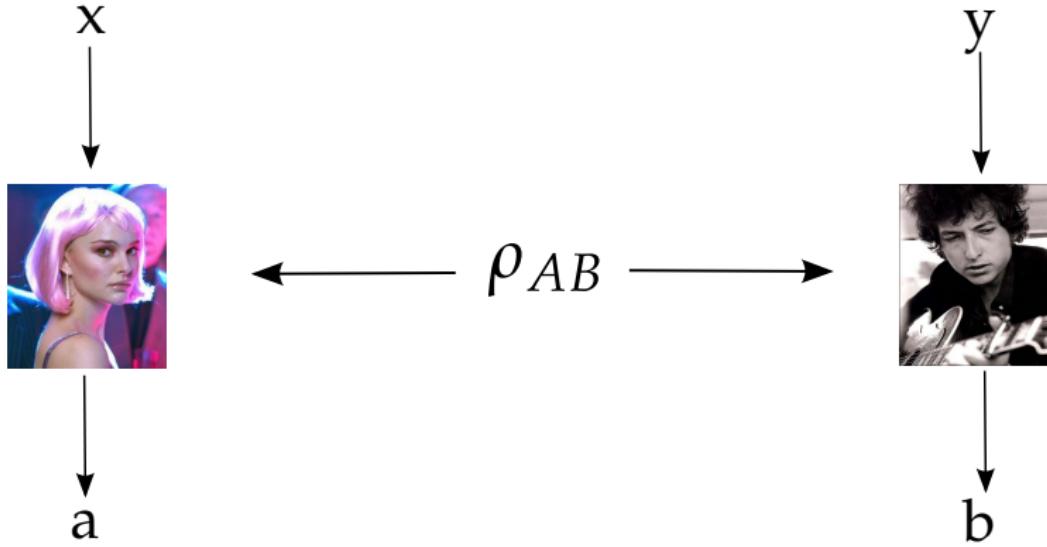
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Discussions

Quantum Experiments



- ▶ Quantum probabilities:

$$p(ab|xy) = \text{tr} (\rho_{AB} A_a^x \otimes B_b^y)$$

- ▶ “Quantum theory is nonlocal” (Bell 64)

$$\text{tr} (\psi_{AB} A_a^x \otimes B_b^y) \neq \int \pi(\lambda) p(a|x\lambda) p(b|y\lambda) d\lambda$$

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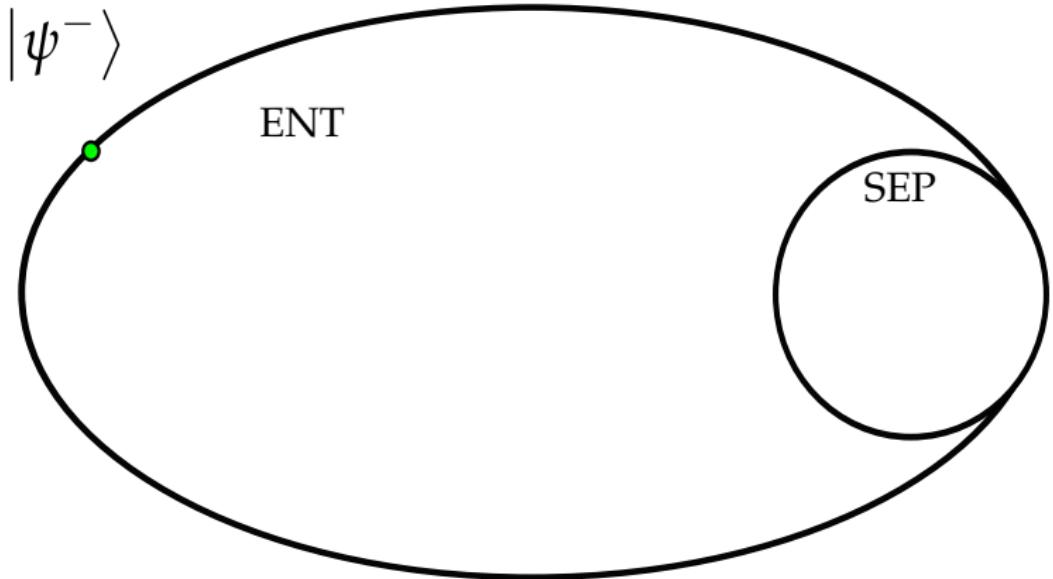
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Discussions

Separable/Entanglement

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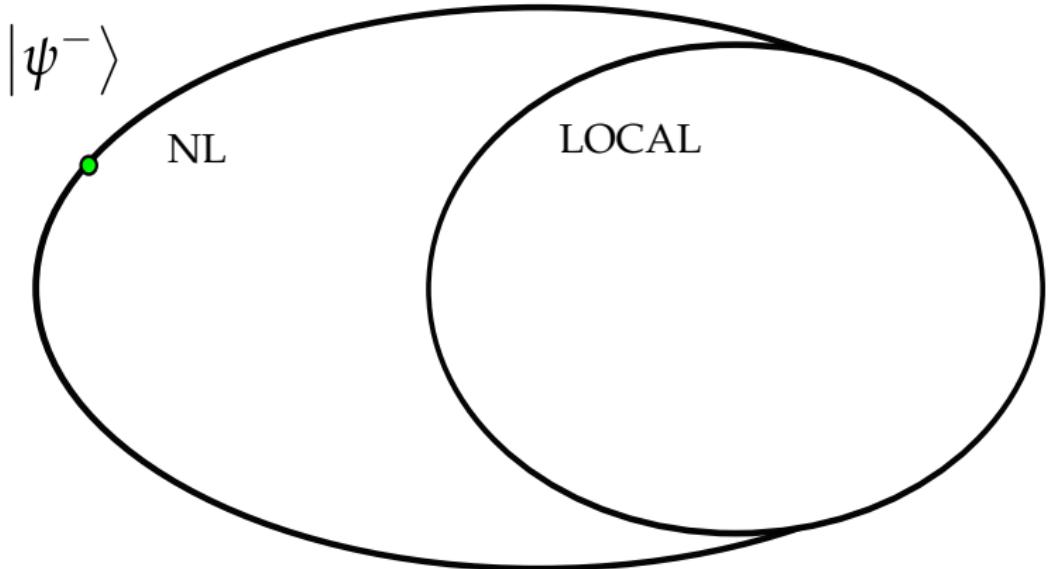
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Local/Nonlocal

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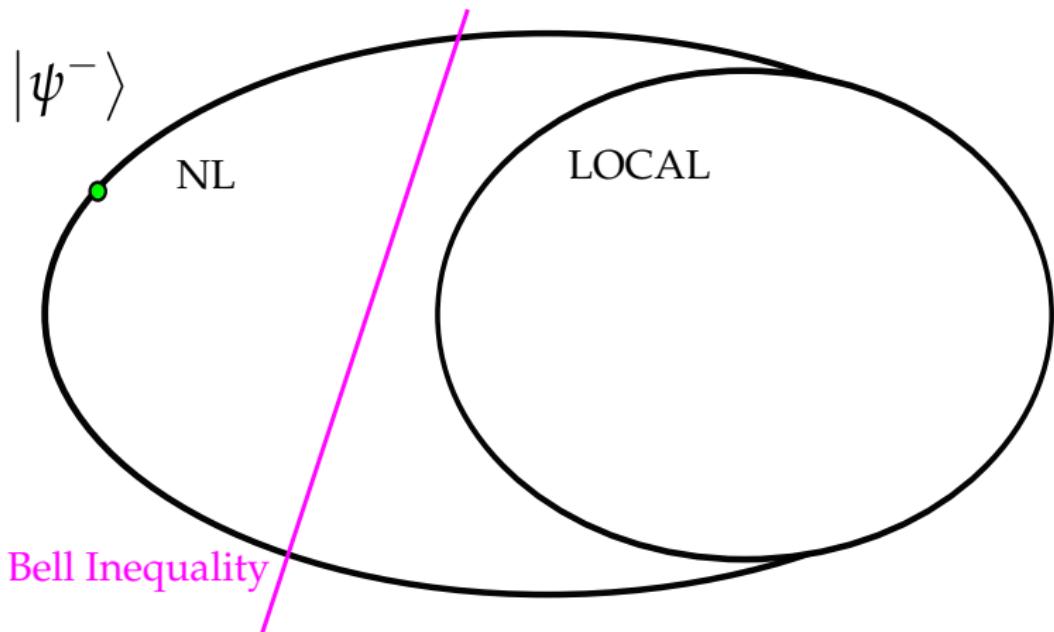
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Discussions

Bell inequalities

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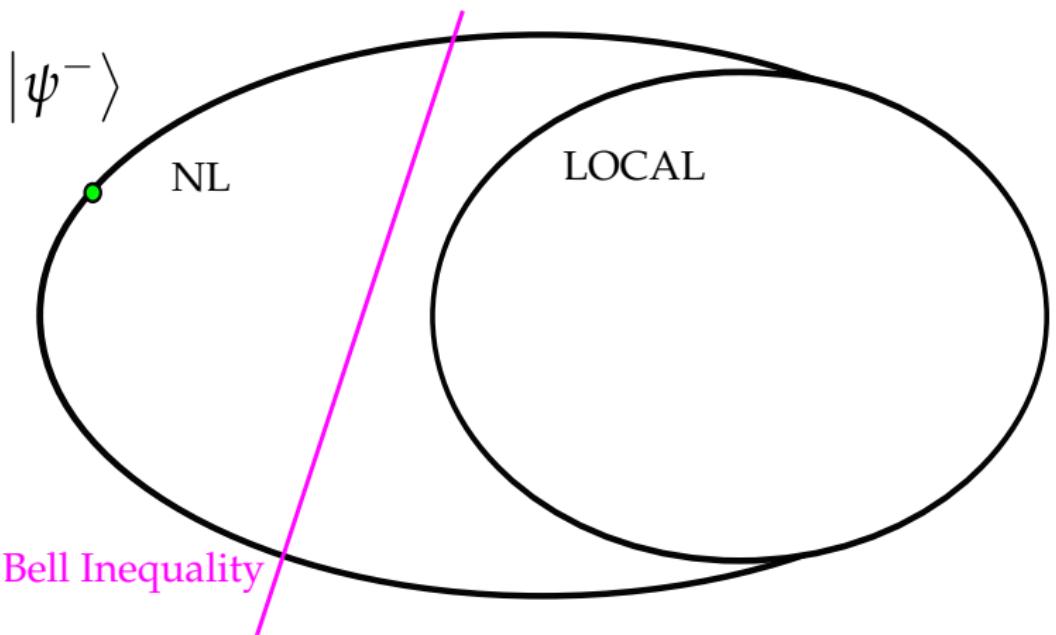
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Discussions

Bell inequalities



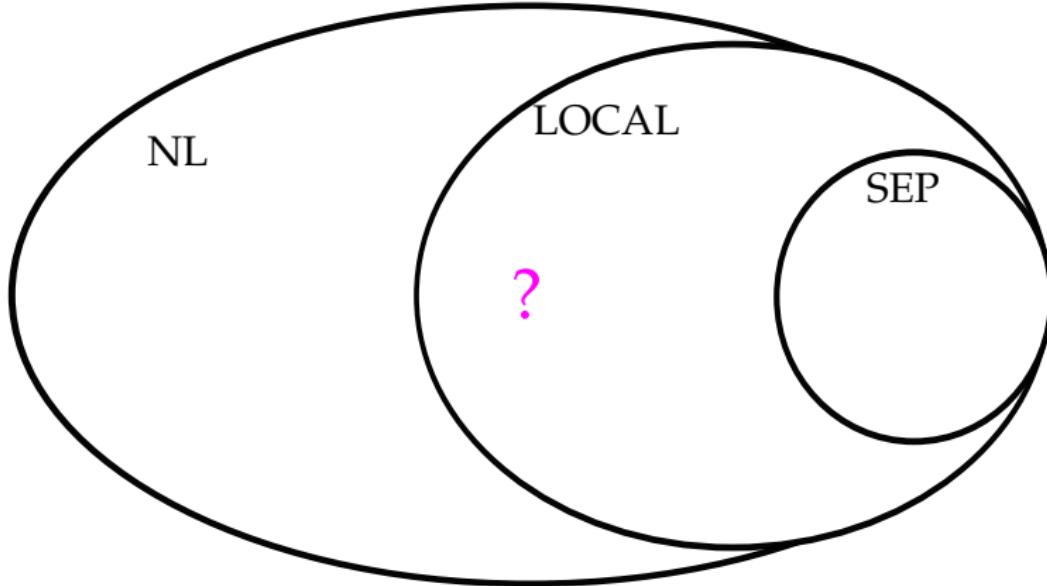
e.g.:

$$CHSH = A_0 \otimes B_0 + A_0 \otimes B_1 + A_1 \otimes B_0 - A_1 \otimes B_1$$

Separable [?] Local

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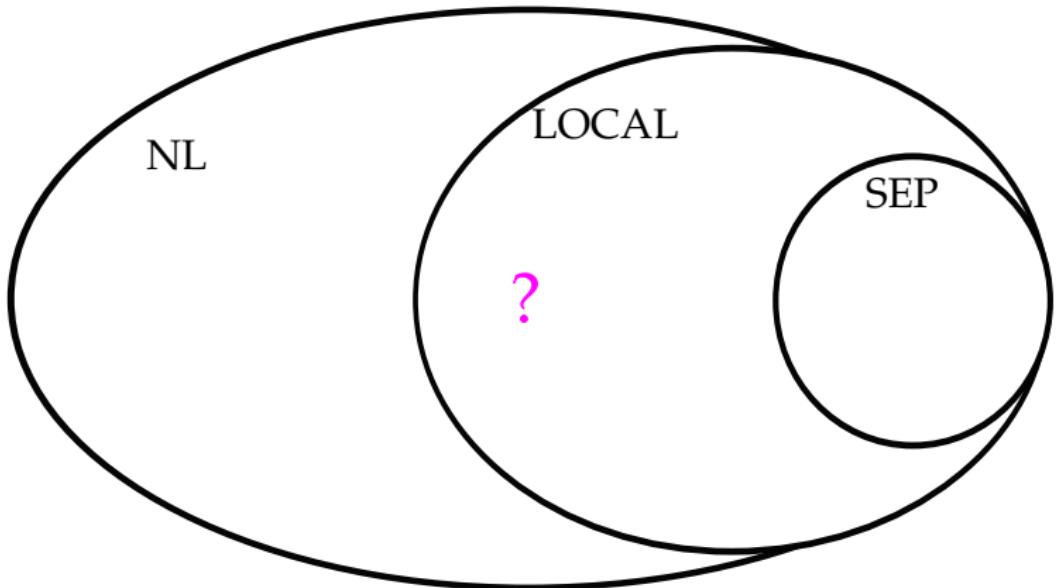
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Discussions

Separable $\stackrel{?}{=}$ Local



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$$p(ab|xy) \neq \int \pi(\lambda) p(a|x\lambda) p(b|y\lambda) d\lambda$$

Entanglement $\overset{?}{\iff}$ Nonlocality

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Entanglement $\overset{?}{\iff}$ Nonlocality

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Entanglement $\overset{?}{\iff}$ Nonlocality

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Discussions

- ▶ Do all entangled states violate a Bell Inequality?
- ▶ Pure states: Yes (Gisin 91, Popescu and Rohrlich 92)
- ▶ Mixed states: ???

Local simulation of quantum states

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Discussions

PHYSICAL REVIEW A

VOLUME 40, NUMBER 8

OCTOBER 15, 1989

Quantum states with Einstein-Podolsky-Rosen correlations admitting a hidden-variable model

Reinhard F. Werner*

Dublin Institute for Advanced Studies, 10 Burlington Road, Dublin 4, Ireland

(Received 1 May 1989)

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Discussions

$$\rho_{AB}$$

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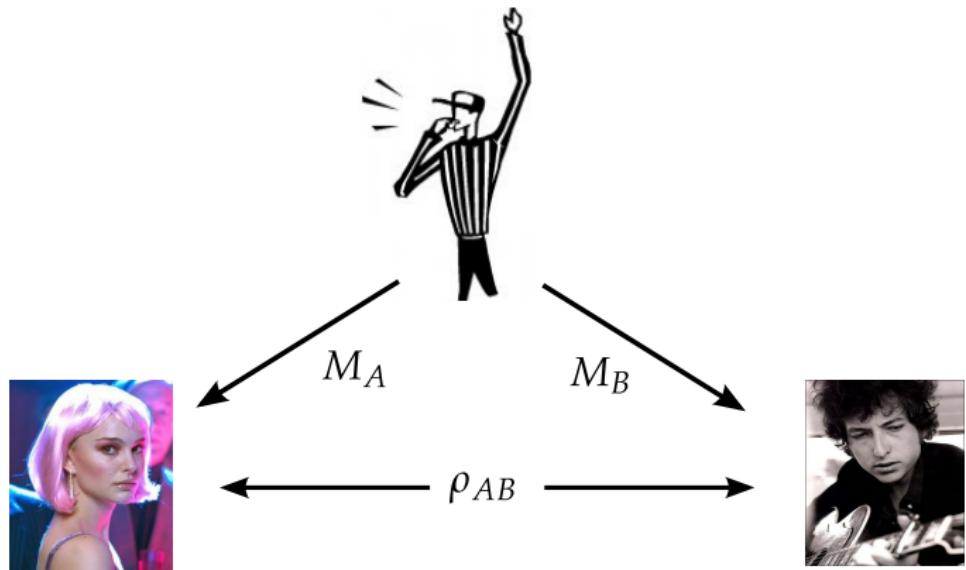
$$\rho_{AB}$$



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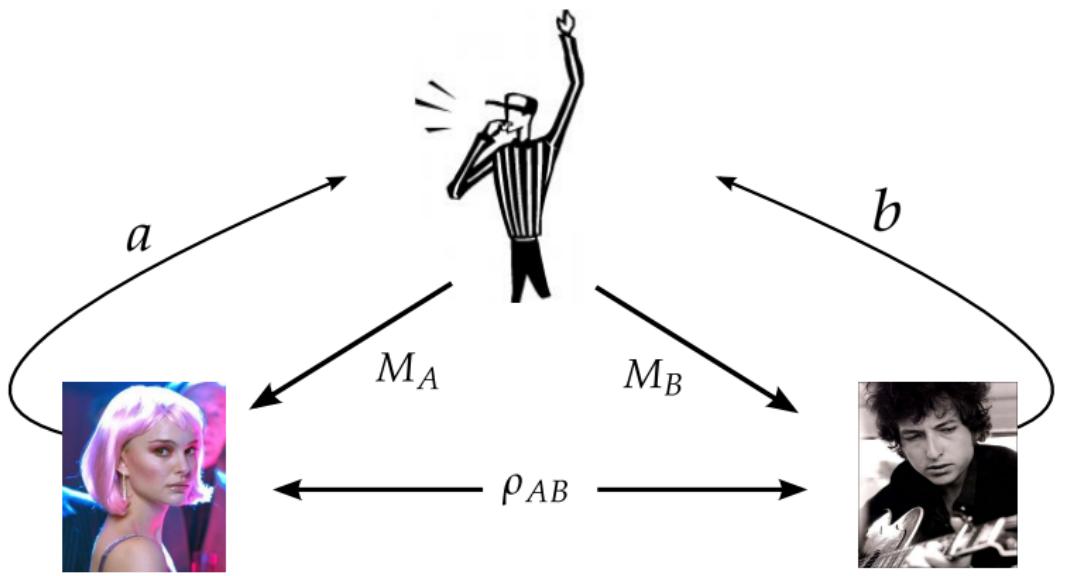
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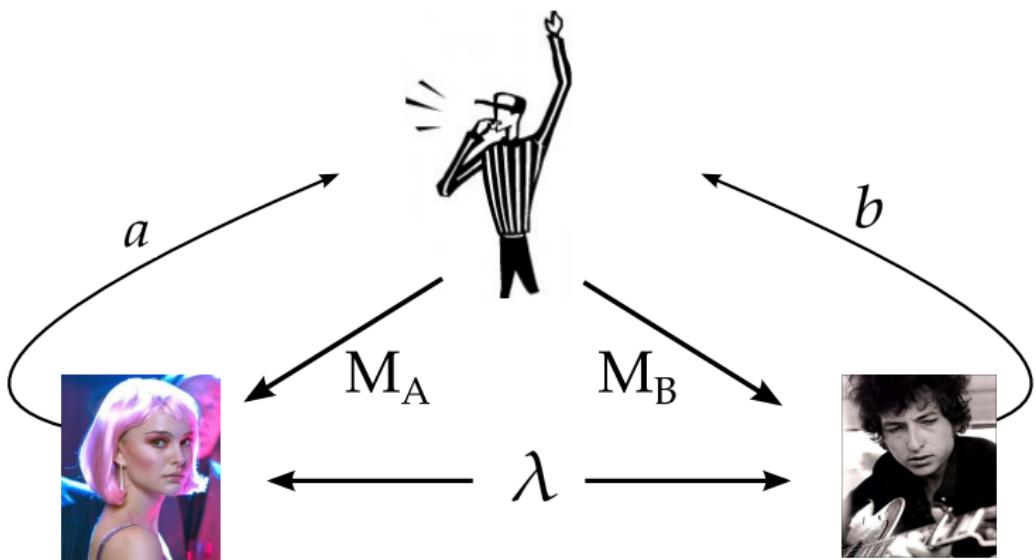
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Local simulation of quantum states

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Local simulation of quantum states

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$$\lambda$$

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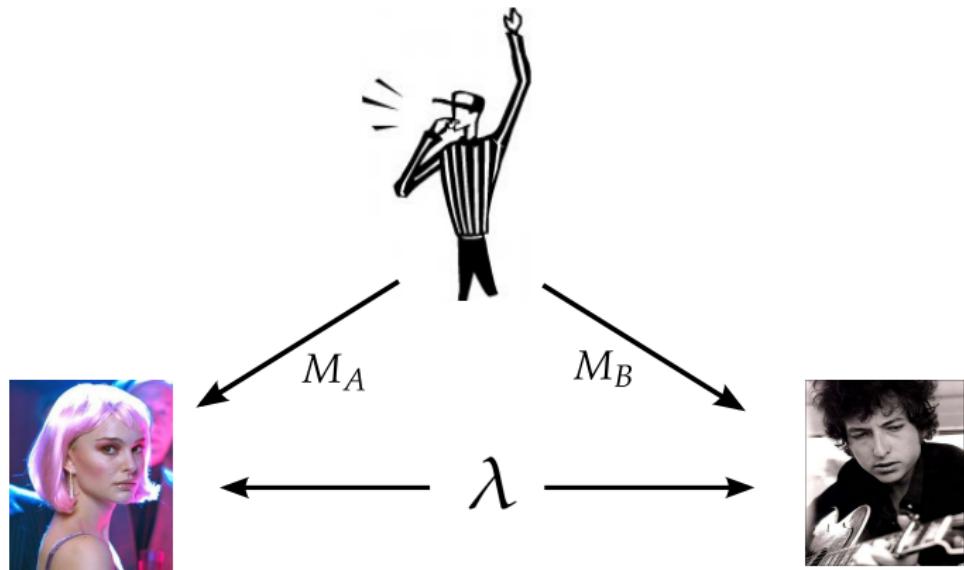
$$\lambda \longleftrightarrow$$



Local simulation of quantum states

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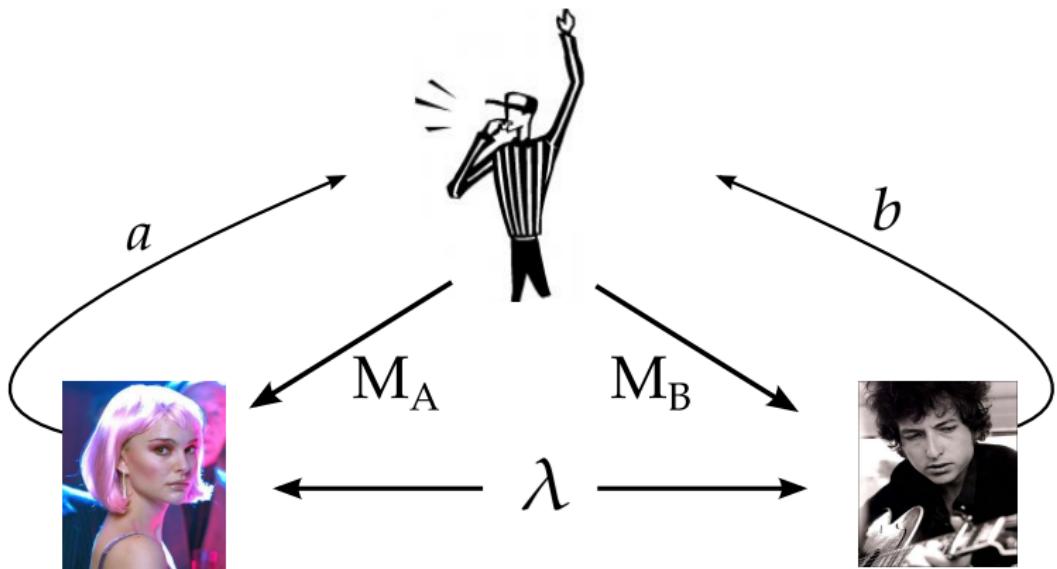
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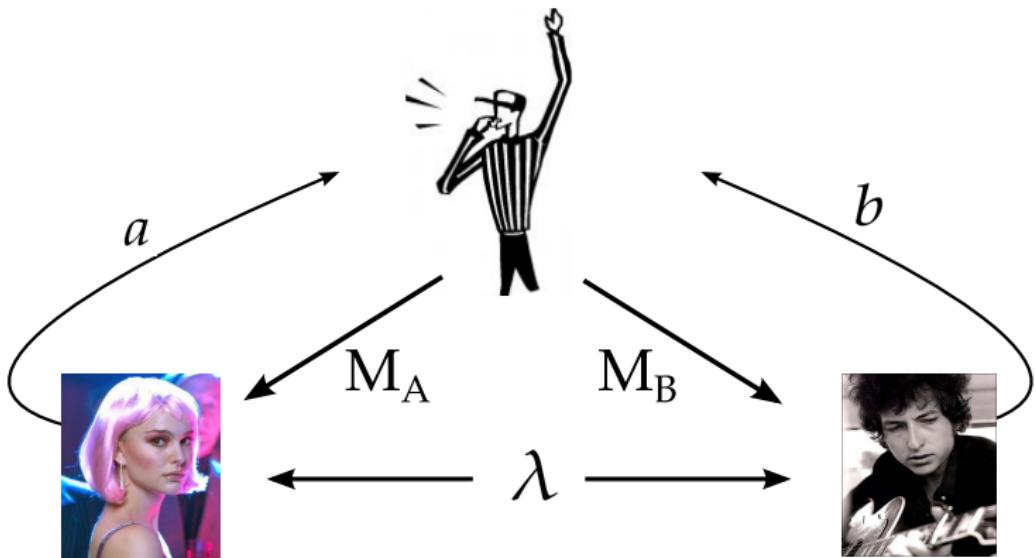
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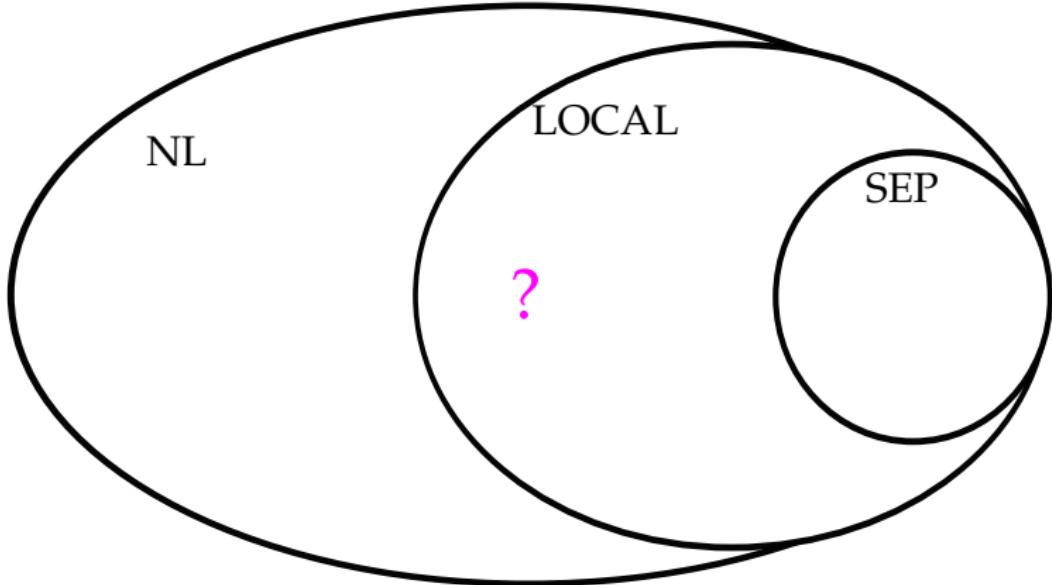


$$\int \pi(\lambda) p_A(a|\lambda) p_B(b|\lambda) d\lambda = \text{tr}(\rho_{AB} M_A^a \otimes M_B^b)$$

Local simulation of quantum states

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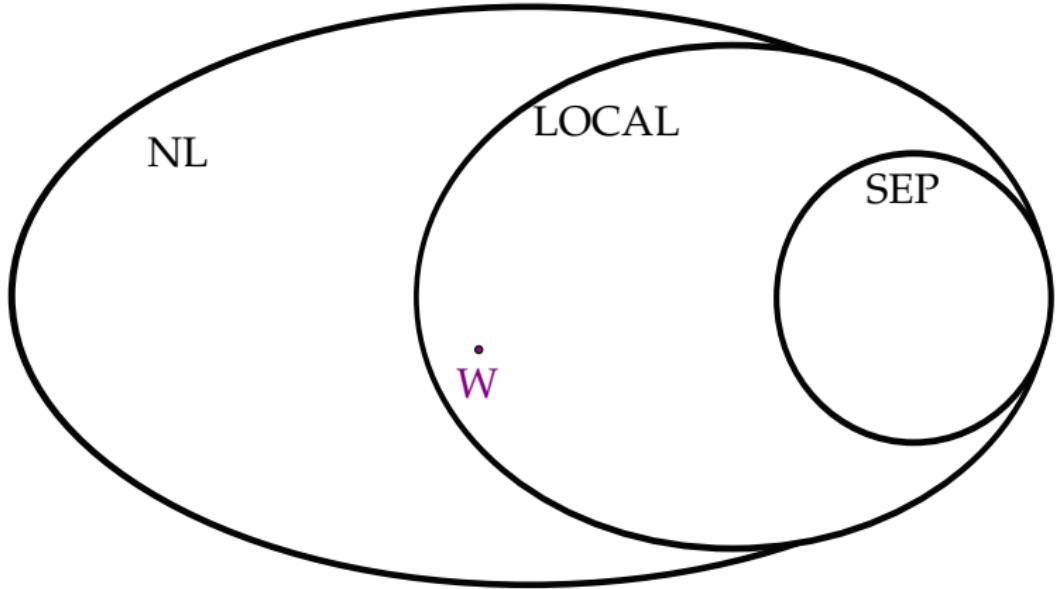
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Local simulation of quantum states

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Discussions

End of story?

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- Entanglement \neq Locality!

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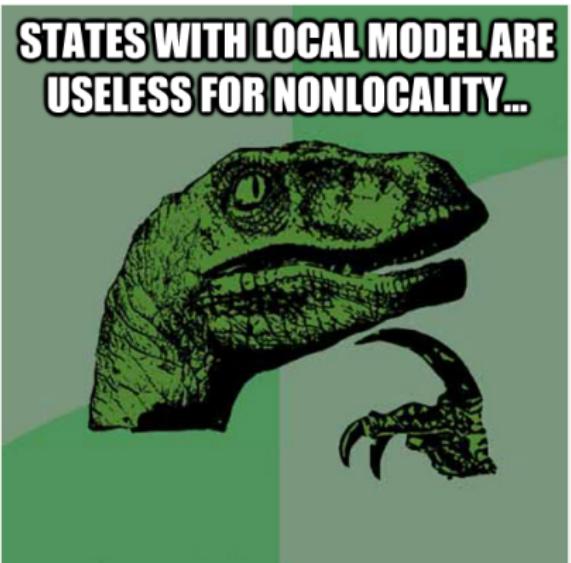
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End of story?

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- ▶ Entanglement \neq Locality!
- ▶ Well...



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POVMs...

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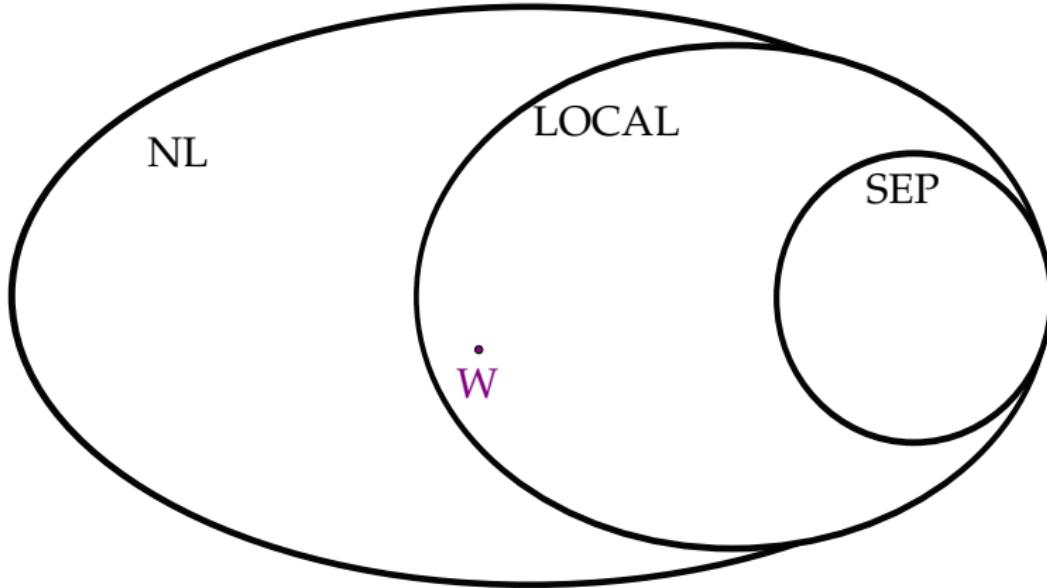
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Local simulation of quantum states

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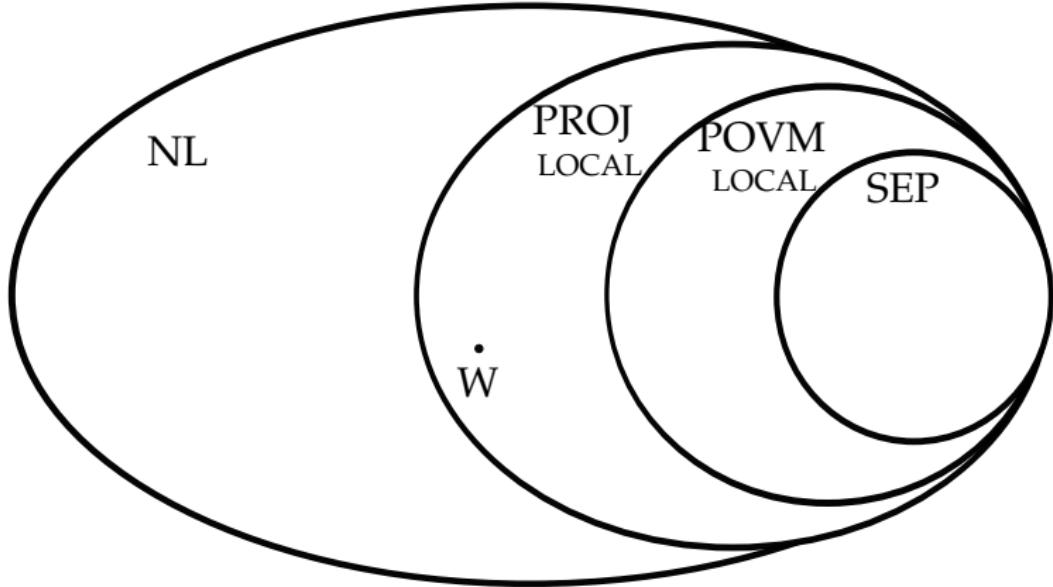
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And if we consider POVMs?

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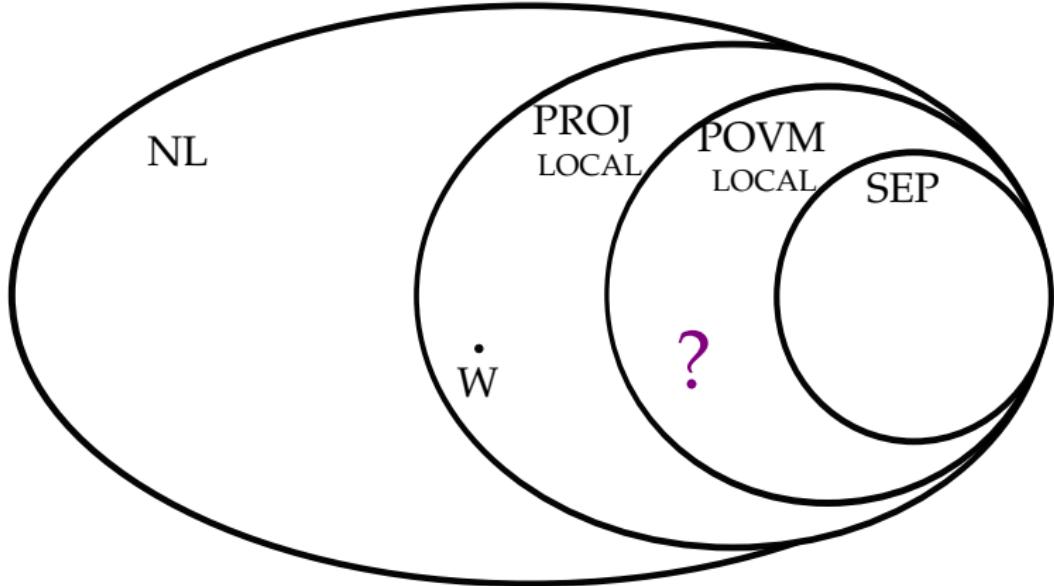
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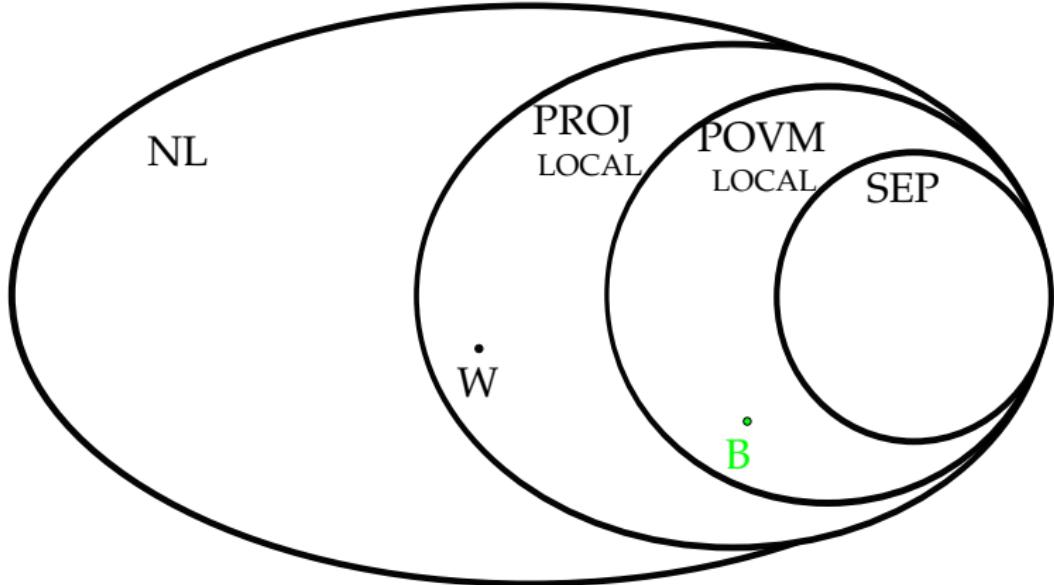
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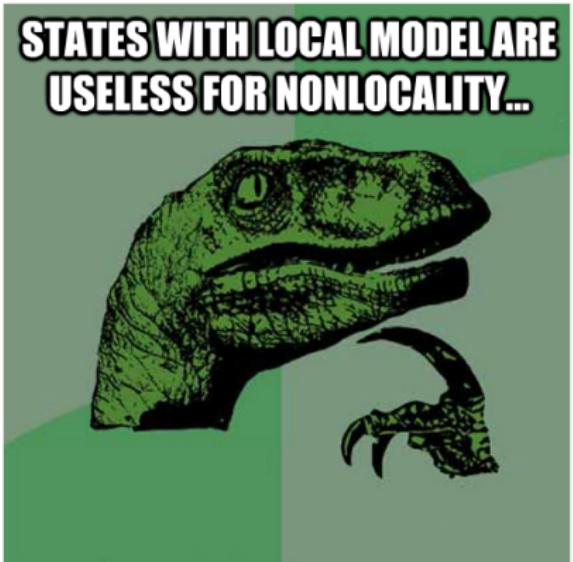
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POVM locality

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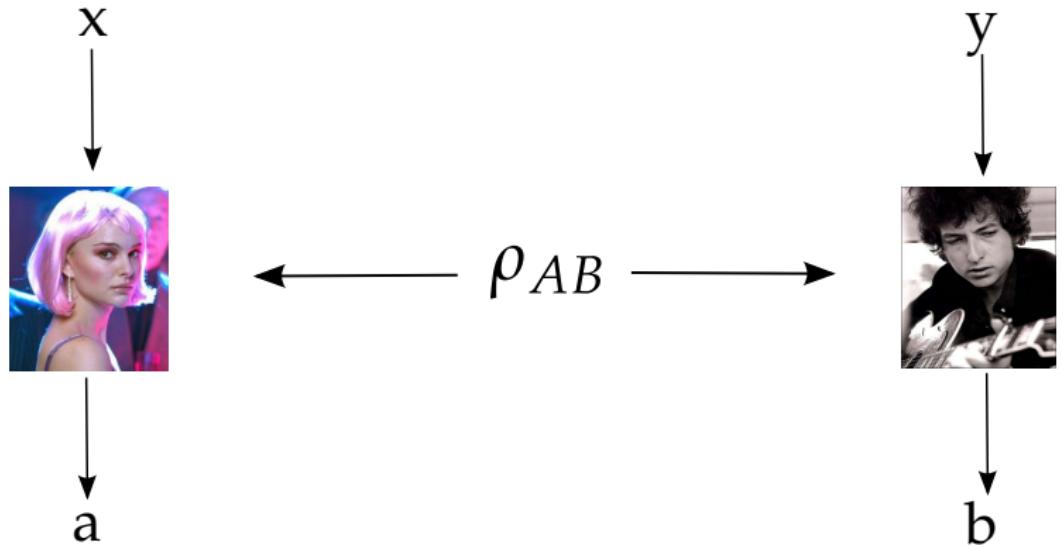
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Single measurement

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Sequential measurements

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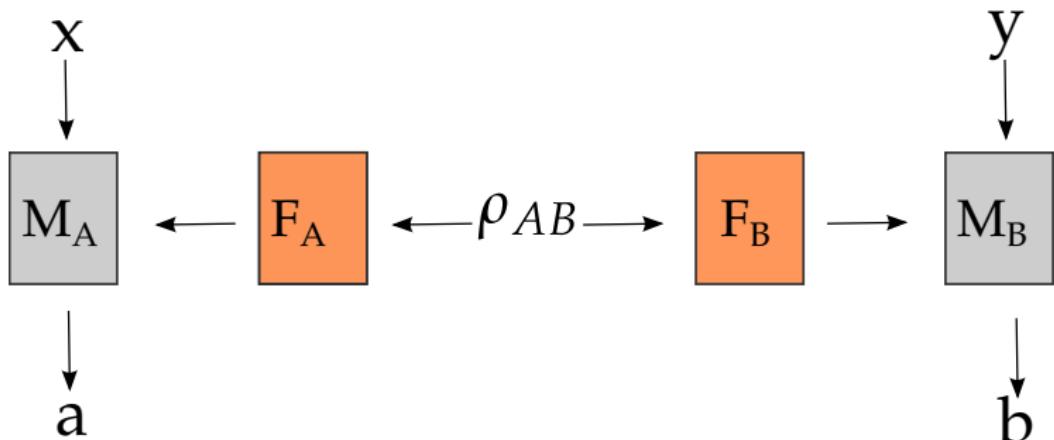
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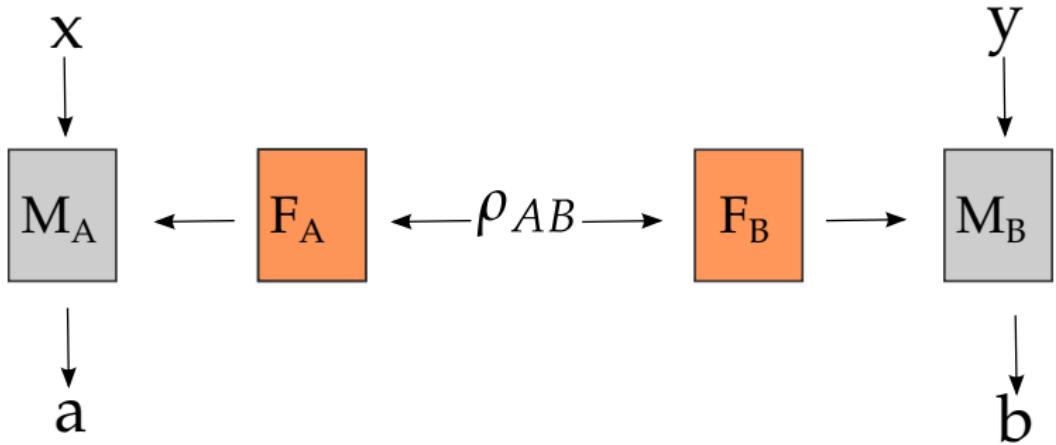
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No additional loophole

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- ▶ Step 1 - Filtering

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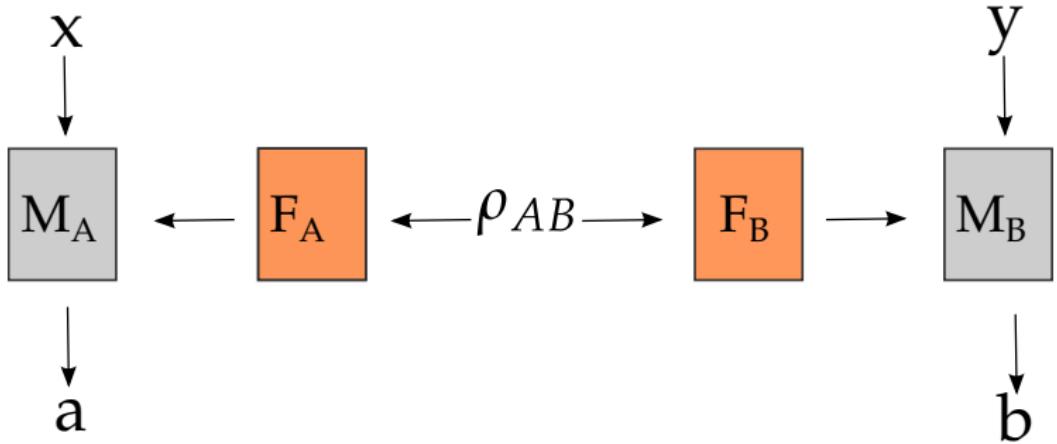
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No additional loophole

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- ▶ Step 1 - Filtering
- ▶ Step 2 - Usual Bell test

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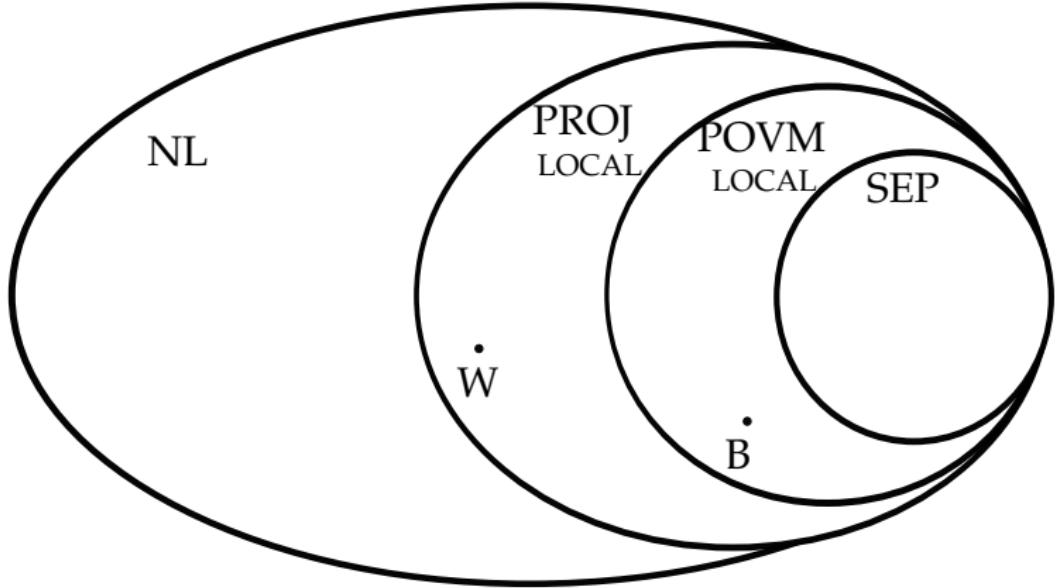
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Hidden Nonlocality

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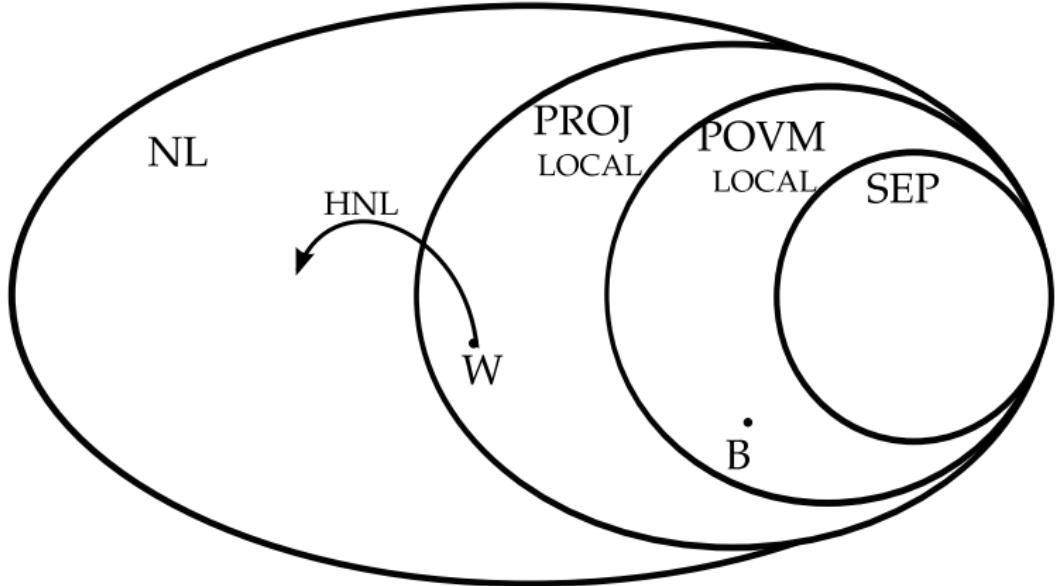
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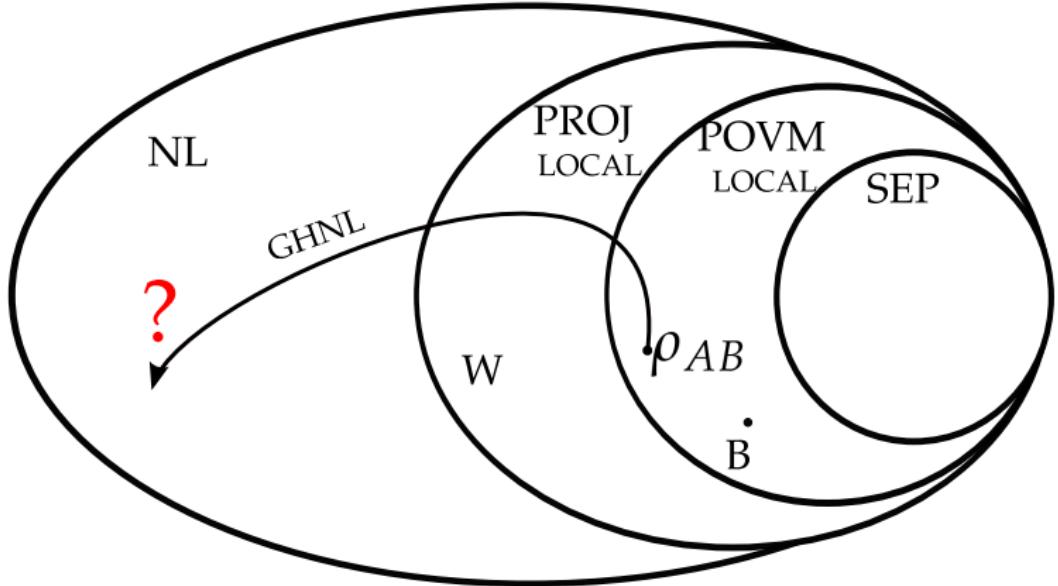
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Genuine Hidden Nonlocality?

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Quantum
Nonlocality

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Quintino



Entanglement Vs.
Nonlocality

Local Entangled
States

POVMs...

Hidden
Nonlocality

Genuine Hidden
Nonlocality

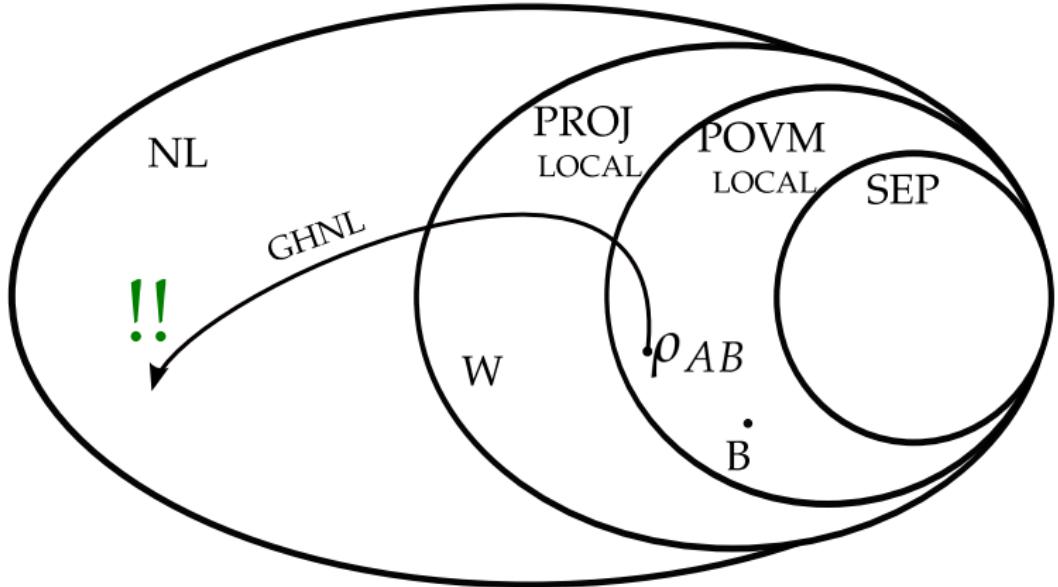
Maximal Genuine
Hidden
Nonlocality

Discussions

Genuine Hidden Nonlocality!!

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Quantum
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Examples of Genuine Hidden Nonlocality

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- ▶ Local model for projective measurements

$$\rho_L = \frac{1}{2} \left(|\psi^-\rangle\langle\psi^-| + |0\rangle\langle 0| \otimes \frac{I}{2} \right)$$

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- ▶ Local model for projective measurements

$$\rho_L = \frac{1}{2} \left(|\psi^-\rangle\langle\psi^-| + |0\rangle\langle 0| \otimes \frac{I}{2} \right)$$

- ▶ If ρ_{AB} is local for projective measurements,

$$\rho'_{AB} = \frac{1}{4} (\rho_{AB} + \rho_A \otimes \sigma_B + \sigma_A \otimes \rho_B + \sigma_A \otimes \sigma_B)$$

is local for all POVMs

ρ_A, ρ_B are the partial trace of ρ_{AB} and σ_A, σ_B are arbitrary qubit states

Examples of Genuine Hidden Nonlocality

- ▶ Local model for projective measurements

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ρ_A, ρ_B are the partial trace of ρ_{AB} and σ_A, σ_B are arbitrary qubit states

- ▶ Genuine hidden nonlocality with qubits!

Examples of Genuine Hidden Nonlocality

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$$\begin{aligned}\rho_G = & \frac{1}{8}|\psi^-\rangle\langle\psi^-| + \frac{3}{8}\left(|0\rangle\langle 0| \otimes \frac{I}{2}\right) \\ & + \frac{1}{8}\left(\frac{I}{2} \otimes |0\rangle\langle 0|\right) + \frac{3}{8}|00\rangle\langle 00|\end{aligned}$$

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$$F_A = F_B = \varepsilon|0\rangle\langle 0| + |1\rangle\langle 1|$$

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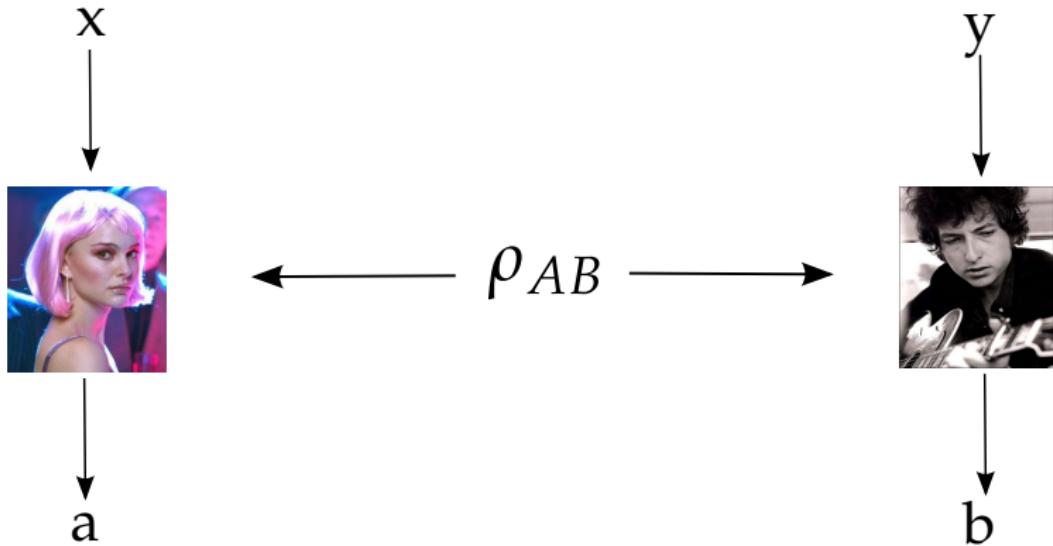
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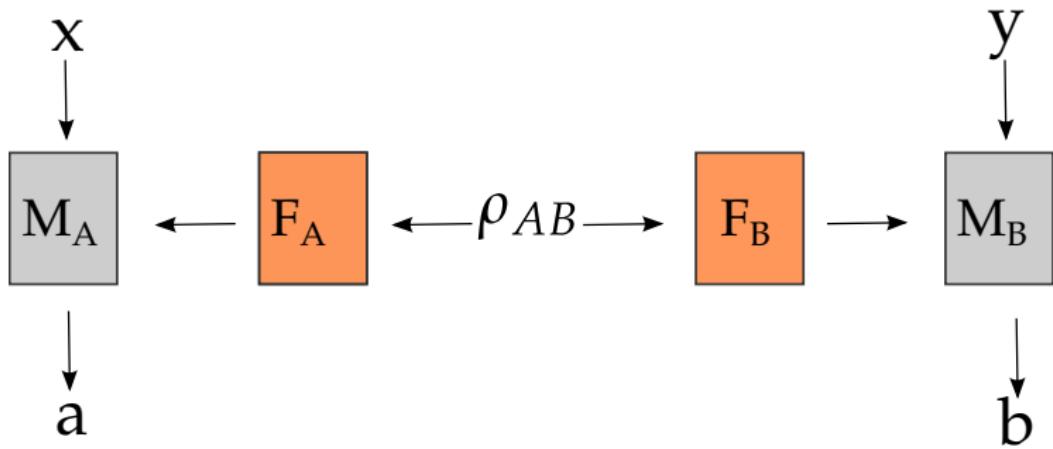


ρ_{AB} is useless

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CHSH violation!!

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Discussions

- ▶ Hidden nonlocality with qudits
- ▶ $\rho_{AB} \mapsto |\psi^-\rangle$ after filtering (2 qutrits)

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Discussions

- ▶ Hidden nonlocality with qudits
- ▶ $\rho_{AB} \mapsto |\psi^-\rangle$ after filtering (2 qutrits)
- ▶ Maximal quantum nonlocality! ($CHSH = 2\sqrt{2}$)

Summary of the results

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Discussions

- ▶ Local model for “asymmetric states”
- ▶ Some completely (POVM) local states have hidden nonlocality

Summary of the results

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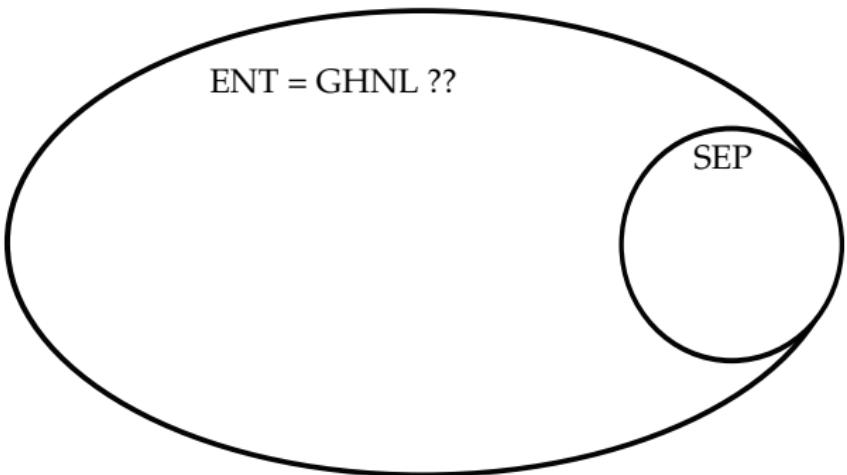
- ▶ Local model for “asymmetric states”
- ▶ Some completely (POVM) local states have hidden nonlocality
- ▶ This phenomenon can be maximal

Related questions

Genuine Hidden
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- ▶ Hidden nonlocal \iff entangled ?



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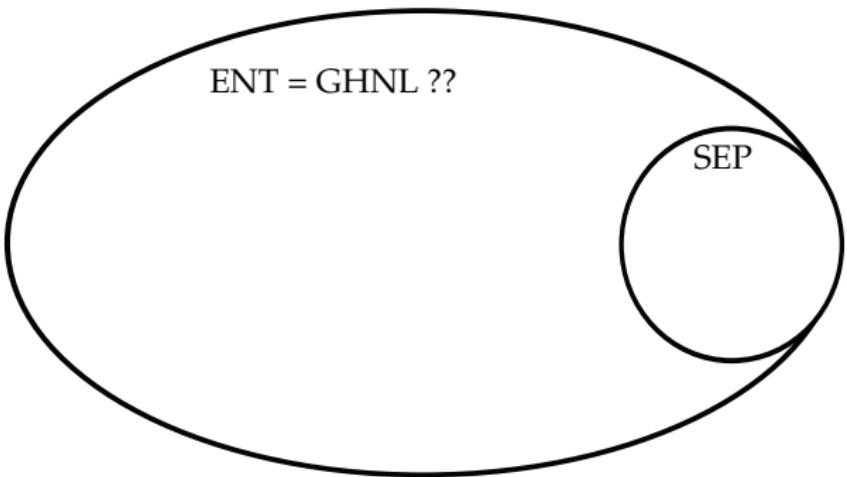
Discussions

Related questions

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- ▶ Hidden nonlocal \iff entangled ?



- ▶ Quantum local states?
Full locality condition?

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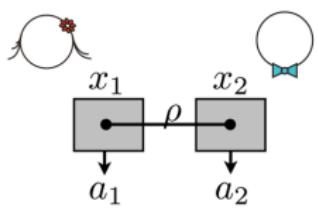
A few more steps

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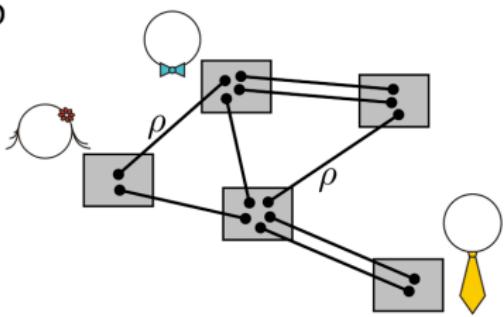
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Activation in networks (Daniel Cavalcanti, Friday 12:00)

a



b



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Discussions

Thank you!

