Title: From Locality to Causality in the Heisenberg Picture

Speakers: Charles Alexandre BÃ©dard

Series: Quantum Foundations, Quantum Information

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From Locality to Causality in the Heisenberg Picture

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CausalWorlds
Perimeter Institue

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Fonds de recherche Nature et technologies Québec
HASLERSTIFTUNG
Università della Svizzera italiana

The Heisenberg picture of unitary quantum theory

A $\quad\quad$ $|\Psi\rangle$ $\quad\quad$ B

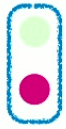
Descriptor $\quad q_A \quad\quad \underbrace{q_A \, , \, q_B}_{q_{AB}} \quad\quad \rightarrow \quad\quad |\Psi\rangle\langle\Psi| \quad\quad q_B$

$\rho_A \quad\quad \rho_A \, , \, \rho_B \quad\quad \not\rightarrow \quad\quad |\Psi\rangle\langle\Psi| \quad\quad \rho_B$

Gottesman, D. (1998). The Heisenberg representation of quantum computers. *arXiv quant-ph/9807006*.

Deutsch, D., & Hayden, P. (2000). Information flow in entangled quantum systems. *PRSA*, 456(1999), 1759-1774.

Descriptors solve problems



$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$

$|\Phi^+\rangle$

$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$

Bell measurement

i, j

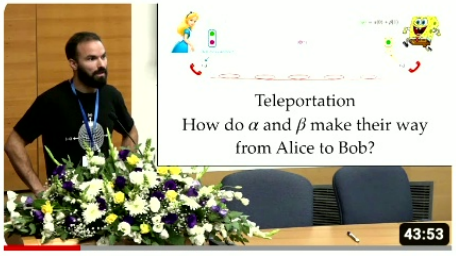
The problem of teleportation

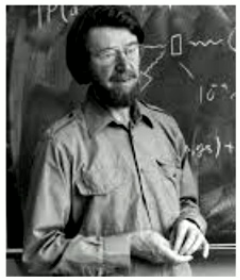
$Z^j X^i$

i, j

How do α and β make their way from Alice to Bob?

Bell





arXiv > quant-ph > arXiv:2406.12184

Quantum Physics

[Submitted on 18 Jun 2024]

The Local Account of Bell Nonlocality

Charles Alexandre Bédard

Bédard, C. A. (2024). The Local Account of Bell Nonlocality. *arXiv:2406.12184*.

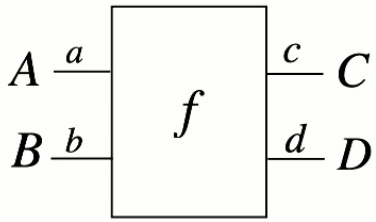
Bédard, C. A. (2023). Teleportation Revealed. *Quantum Reports*, *5*(2), 510-525.

Deutsch, D., & Hayden, P. (2000). Information flow in entangled quantum systems. *PRSA*, 456(1999), 1759-1774.

Causal models with descriptors

The starting point: no influence criterion

Dilation of a classical stochastic theory

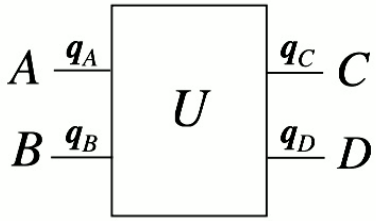


'A does not influence D'

$\Longleftrightarrow$ d is independent of a

$d = f(a, \bar{a}) = f'(\bar{a})$

Unitary quantum theory



'A does not influence D'

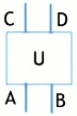
$\Longleftrightarrow$ $\boldsymbol{q}_D$ is independent of $\boldsymbol{q}_A$

Allen, J. M. A., Barrett, J., Horsman, D. C., Lee, C. M., & Spekkens, R. W. (2017). Quantum common causes and quantum causal models. *Physical Review X*, *7*(3), 031021. [ABHLS 2017]

Barrett, J., Lorenz, R., & Oreshkov, O. (2019). Quantum causal models. *arXiv preprint arXiv:1906.10726*. [BLO 2019]

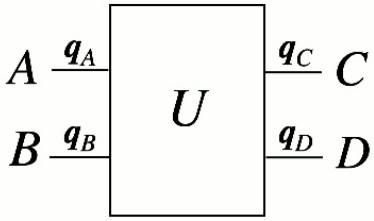
Causal influence in unitary transformations

Definition:

For a generic bipartite unitary U: 

say that A *does not influence* D if:

- for all inputs ρ_B, the marginal ρ_D is independent of ρ_A
- equivalently, $\mathrm{Tr}_C\ \rho^U_{CD|AB} = \rho_{D|B} \otimes I_A$



DH's descriptors (2000)

$$(q_C\ ,\ q_D) = q_{CD}$$

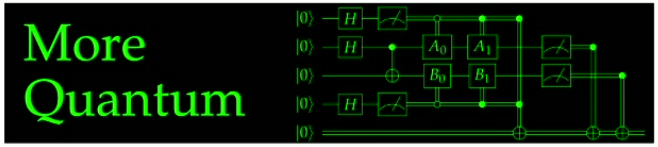
★

*

Choi-Jamiołkowski representation of U and traces thereof

Raymond-Robichaud's evolution matrices (2021)

$$[U]^C \odot [U]^D = [U]^{CD}$$



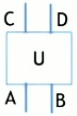
Barrett, J. (2021). Causal Influence in Quantum Theory. *Quantum Boundaries.*

✻ Araújo, M. (2020). Explicitly local quantum mechanics. *More Quantum.*

★ Bédard, C. A. (2021). The cost of quantum locality. *Proceedings of the Royal Society A, 477*(2246), 20200602.

Causal influence in unitary transformations

Definition:

For a generic bipartite unitary U: 

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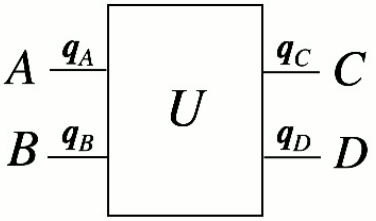
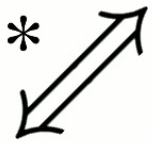


Descriptor D — Does not depend on descriptor A

DH's descriptors (2000)

$$(q_C\ ,\ q_D) = q_{CD}$$



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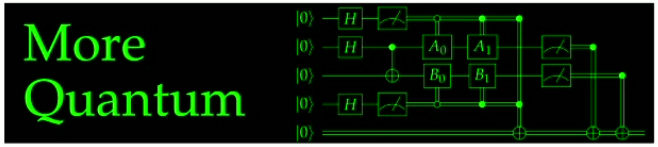

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References

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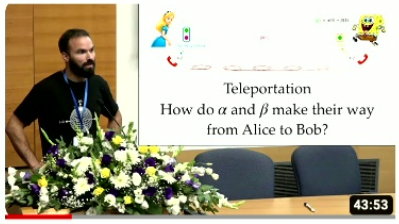

Quantum locality:
Unification, cost and consequences

Allen, J. M. A., Barrett, J., Horsman, D. C., Lee, C. M., & Spekkens, R. W. (2017). Quantum common causes and quantum causal models. *Physical Review X*, *7*(3), 031021.

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Gottesman, D. (1998). The Heisenberg representation of quantum computers. *arXiv quant-ph/9807006*.

Raymond-Robichaud, P. (2021). A local-realistic model for quantum theory. *Proceedings of the Royal Society A*, *477*(2250), 20200897.