University of Gdańsk

Causality beyond Quantum Theory: The Causaloid Framework

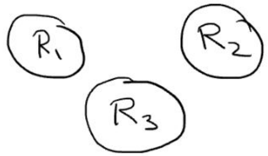
Nitica Sakharwade (ICTQT, Gdansk, Poland)
Work with: Natalia Moller

International Centre for Theory of Quantum Technologies

How can we understand the Process Matrix Formalism within the Causaloid Framework?

Causaloid Framework

for three regions



$$\Lambda = \{ \Lambda^{k_1}_{l_1}, \Lambda^{k_2}_{l_2}, \Lambda^{k_3}_{l_3}, \Lambda^{k_1k_2}_{l_1l_2}, \Lambda^{k_2k_3}_{l_2l_3}, \Lambda^{k_1k_3}_{l_1l_3}, \Lambda^{k_1k_2k_3}_{l_1l_2l_3} \}$$

where

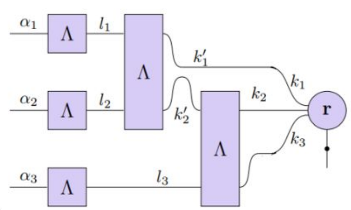
$$\Lambda = \{ \Lambda^{k_1}_{l_1}, \Lambda^{k_2}_{l_2}, \Lambda^{k_3}_{l_3}, \Lambda^{k_1k_2}_{l_1l_2}, \Lambda^{k_2k_3}_{l_2l_3} \}$$

1) 2nd rung of hierarchy

2) $R_1 \bowtie R_2$

$R_2 \bowtie R_3$

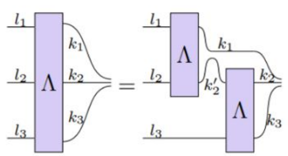
causally adjacent



$l_i \in \Omega_i$

$k_i k_j \in \Omega_{ij}$

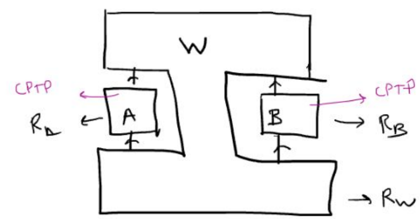
$\Omega_{ij} \subseteq \Omega_i \times \Omega_j$



$$\equiv \Lambda^{k_1k_2k_3}_{l_1l_2l_3} = \sum_{k_2'} \Lambda^{k_2k_3}_{k_2'l_3} \Lambda^{k_1k_2'}_{l_1l_2}, \quad k_2' \in \Omega_{\gamma,2}$$

where $\Omega_{1,2,3} = (\Omega_{1,2} \times \Omega_3) \cap (\Omega_1 \times \Omega_{2,3})$

Process Matrix (Bipartite)



$\Omega_A = \{ \mathbb{1}, \sigma_i^{A_2}, \sigma_i^{A_1}\sigma_j^{A_2} \}$

$\Omega_B = \{ \mathbb{1}, \sigma_i^{B_2}, \sigma_i^{B_1}\sigma_j^{B_2} \}$

$\Omega_W = \{ \mathbb{1}, \sigma_i^{A_1}, \sigma_i^{B_1}, \sigma_i^{A_1}\sigma_j^{B_1}, \sigma_i^{A_1}\sigma_j^{B_2}, \sigma_i^{A_2}\sigma_j^{B_1}, \sigma_i^{A_1}\sigma_j^{A_2}\sigma_k^{B_1}, \sigma_i^{A_1}\sigma_j^{B_1}\sigma_k^{B_2} \}$

$\Omega_{AB} = \Omega_A \times \Omega_B$

$\Omega_{AW} = \{ \mathbb{1}, \sigma_i^{B_1} \}$

$\Omega_{BW} = \{ \mathbb{1}, \sigma_i^{A_1} \}$

$\Omega_{ABW} = \{ \mathbb{1} \}$

Satisfies $\Omega_{AWB} = (\Omega_{AW} \times \Omega_B) \cap (\Omega_A \times \Omega_{WB})$

All Bipartite Process Matrices fall in the 2nd rung of the Hierarchy.
(Quantum theory theory also belongs to the same rung)

[1] Hardy, L. (2005). Probability theories with dynamic causal structure: a new framework for quantum gravity. *arXiv preprint gr-qc/0509120*..
[2] Sakharwade, N. (2022). An Operational Road towards Understanding Causal Indefiniteness within Post-Quantum Theories, UWSpace http://hdl.handle.net/10012/17841

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