Title: Subsystem decompositions of quantum circuits and transformations between causal perspectives

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Subsystem decompositions of quantum circuits and transformations between causal perspectives

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joint work with Ognyan Oreshkov

Causalworlds 2024

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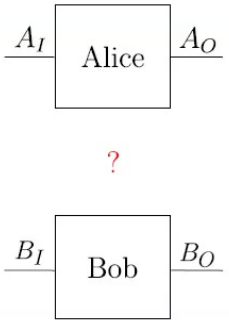
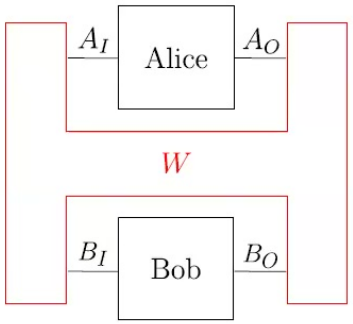
Indefinite causal order

Abstract formalism: **Process matrix framework**[1]

- Several parties performing quantum operations
- No **a priori** causal order
- How can the parties be connected?



- Most generally: **Process matrix**
  - ↪ Can be incompatible with a well-defined causal order!



[1] O. Oreshkov, F. Costa, Č. Brukner, Nat. Commun. 3, 1092 (2012)

Physical meaning of indefinite causal order

- **Central open question**: physical interpretation / operational meaning of indefinite causal order?

- Operational understanding for certain causally indefinite processes: based on **time-delocalised subsystems** / **time-delocalised operations**[1,2]

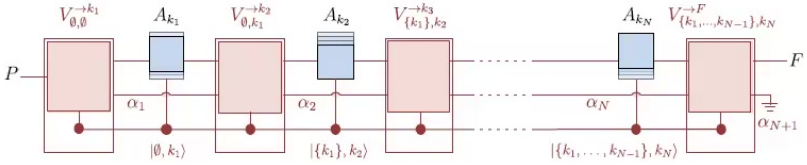
  ↪ Can occur as part of standard quantum temporal evolutions, in which the operations that are composed in an indefinite causal order **extend over multiple time steps**

  ↪ Formal link with abstract process matrix framework: **change of the quantum systems** into which the process is partitioned

[1] O. Oreshkov, Quantum 3, 206 (2019)

[2] J. Wechs, C. Branciard, O. Oreshkov, Nat. Commun. 14, 1471 (2023)

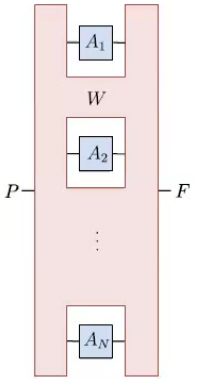
Time-delocalised operations



Temporal description with time-delocalised operations

$\Longleftrightarrow$

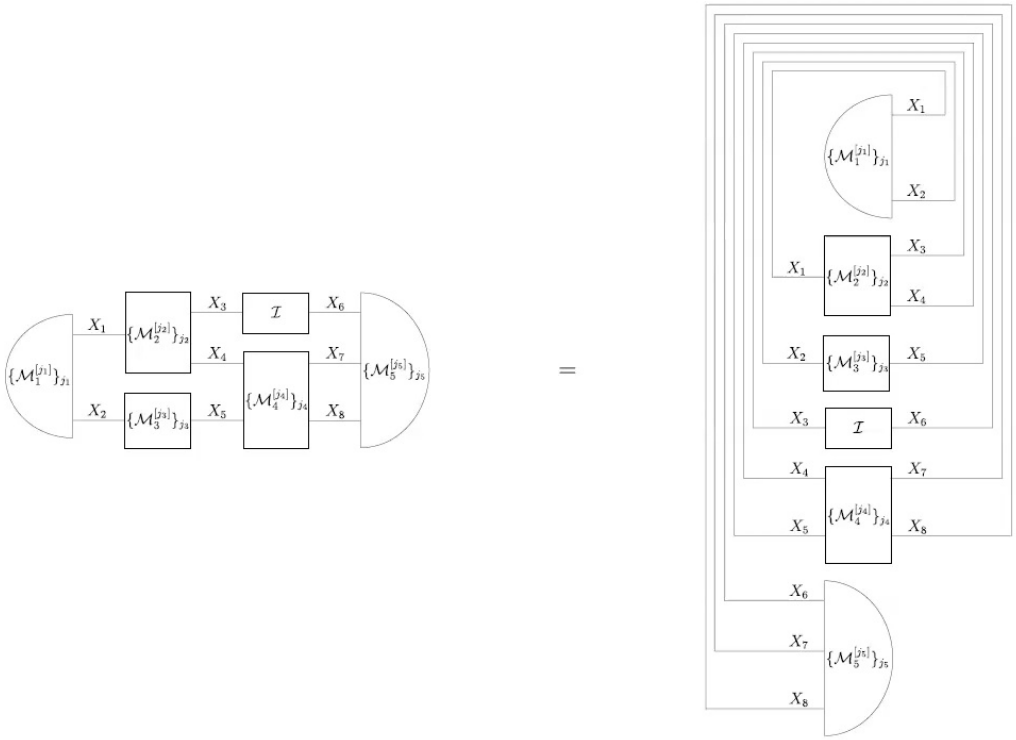
Subsystem change



Process matrix description

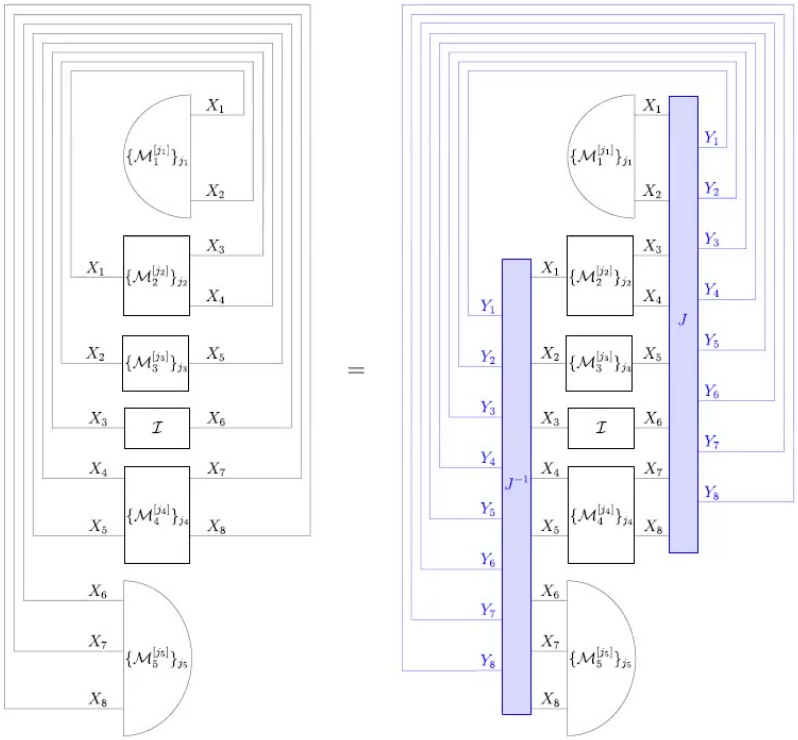
- General formalisation of transformations between different subsystem decompositions of temporal evolutions
- Transformations between **causal perspectives** in the quantum switch

Subsystem decompositions of quantum circuits



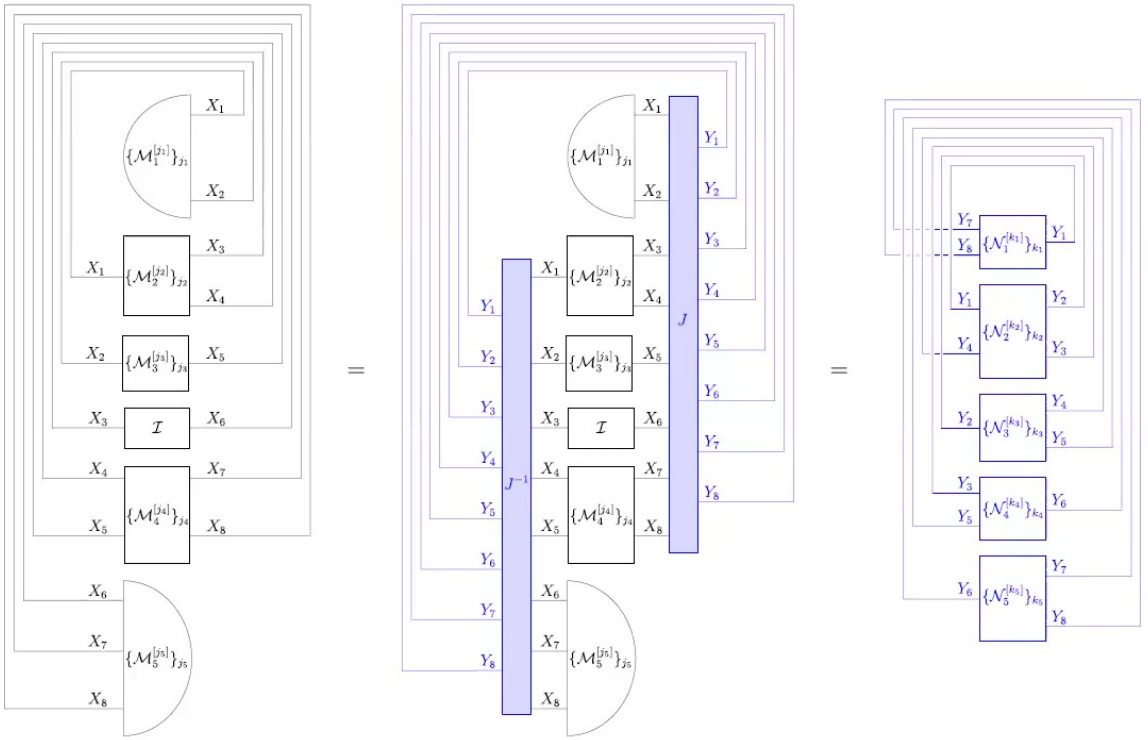
"Circuit operation" consisting of the tensor product of all operations
$\rightarrow$ Acts on the joint Hilbert space of all systems in the circuit

Subsystem decompositions of quantum circuits



Alternative subsystem decomposition $\rightarrow$ Isomorphism J defining another tensor factor decomposition of that joint Hilbert space

Subsystem decompositions of quantum circuits

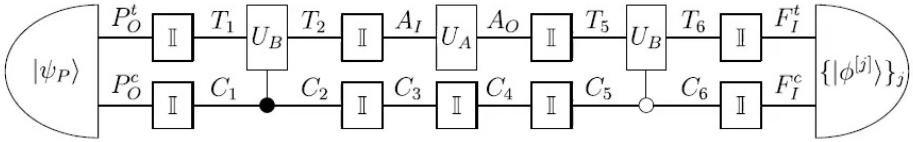


New (possibly cyclic) circuit description with operations acting on new (possibly time-delocalised) subsystems

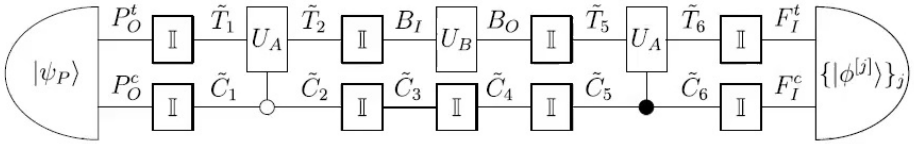
Transformations between causal perspectives[1]

Temporal circuits describing **causal perspectives** in the quantum switch:

↪ Alice's operation localised in time



↪ Bob's operation localised in time



↪ No subsystem transformation exists to change between causal perspectives

[1] J. Wechs, O. Oreshkov, in preparation