Causal Models Cannot Explain QM Correlations in Extended Wigner's Friend Scenarios **

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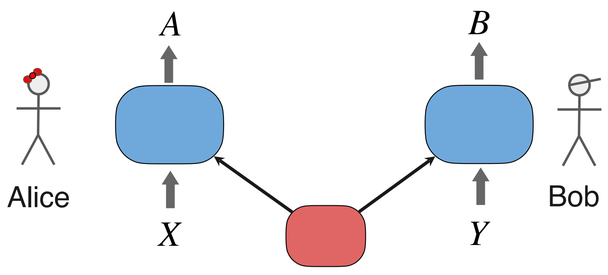
Bell Scenario

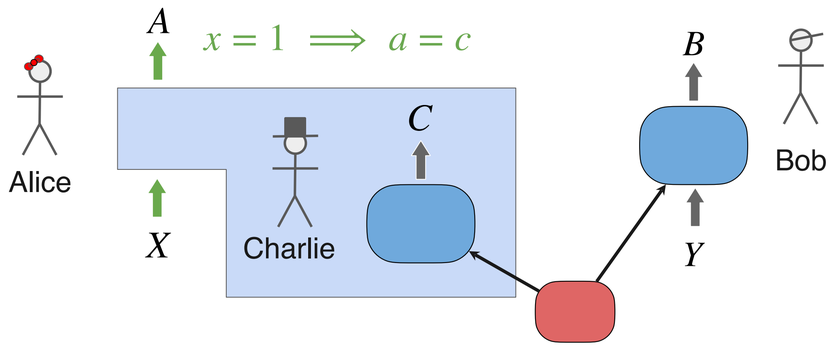


Observed conditional independences

$A \perp Y|X \qquad B \perp X|Y$

Violation of the Bell inequalities

Local Friendliness Scenario



Observed conditional independences

$A \perp Y|X \qquad B \perp X|Y$

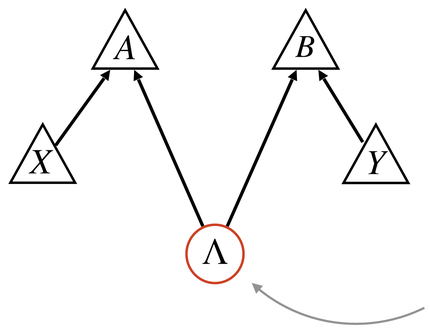
Violation of the Local Friendliness inequalities [3]

(**if** QM is universally applicable)

[3] KW. Bong, A. Utreras-Alarcón, F. Ghafari, *et al.* Nature Physics. 16, 1199–1205 (2020)

Classical Causal Modelling

BELL DAG



Causal explanation =
causal structure
+ compatible distribution

Λ is a classical variable

Markov condition
Pearl's classical causal modelling [1,2]

$$P(abxy) = \sum_{\lambda} p(a|x\lambda)p(b|y\lambda)p(\lambda)p(x)p(y)$$

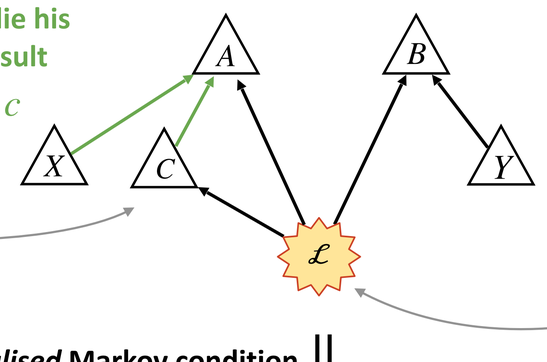
$A \perp Y|X$ $\qquad$ $B \perp X|Y$ $\qquad$ **Bell Inequalities**

[1] C. Wood and R. Spekkens, New Journal of Physics, 17, 08 (2012)
[2] J. Pearl. Causality: Models, Reasoning and Inference. Cambridge University Press (2009)

GPT Causal Modelling

Alice can ask Charlie his measurement result

$x = 1 \implies a = c$

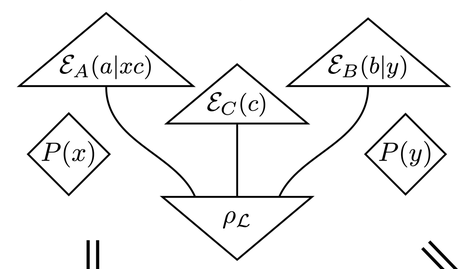


Observed events have classical values

$\mathcal{L}$ is a system in *some* GPT

LF DAG

***Generalised* Markov condition**
Henson, Lal and Pusey's framework [4]



$$P(abxy) = \sum_{c}$$

A GPT diagram with no dangling wires is a probability distribution

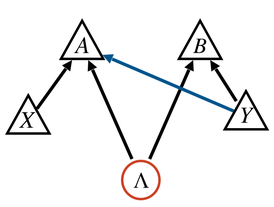
From d-separations relations and $x = 1 \implies a = c$

$A \perp Y|X$ $\qquad$ $B \perp X|Y$ $\qquad$ **Local Friendliness Inequalities**

[4] J. Henson, R. Lal, and MF. Pusey. New Journal of Physics 16(11):113043, (2014)

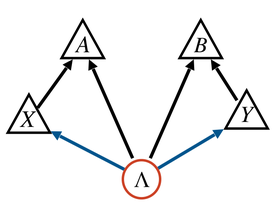
All Classical Causal Explanations are Finetuned

Superluminal Causation



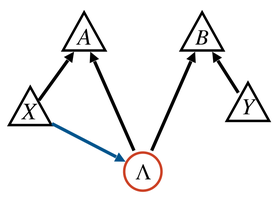
$A \not\perp_d Y|X$

Superdeterminism



$A \not\perp_d Y|X \wedge B \not\perp_d X|Y$

Retrocausality



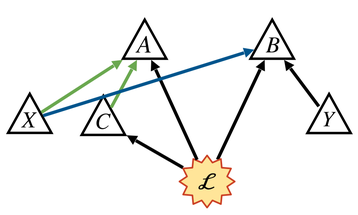
$B \not\perp_d X|Y$

DAGs compatible with **the violation of Bell's inequalities** are **finetuned** wrt some observable conditional independence.

(They are also in tension with relativistic principles and with the description of the experiment)

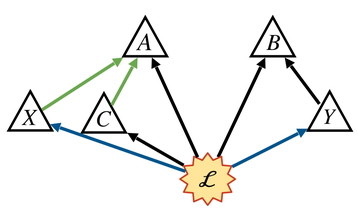
All GPT Causal Explanations are Finetuned

Superluminal Causation



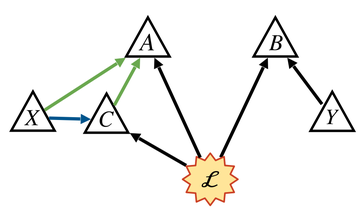
$B \not\perp_d X|Y$

Superdeterminism



$A \not\perp_d Y|X \wedge B \not\perp_d X|Y$

Retrocausality



$C \not\perp_d X$

DAGs compatible with **the violation of Local Friendliness inequalities** are **finetuned** wrt some observable (*or postulated*) conditional independence.

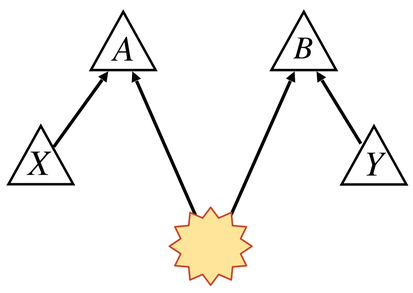
(They are also in tension with relativistic principles and with the description of the experiment)

(Generalises to a wide class of cyclic causal models too!)

No finetuning principle:
each conditional independence relation in the data implies a corresponding d-separation relation in the DAG

The Wood+Spekkens Solution [1]: Quantum / GPT causal modelling

Keep the causal structure,
change the rule for compatible distributions



Explains experimental data

No finetuning

Quantum / GPT common cause explanation

A problem in need of a solution

Weird behaviour inside a Wigner bubble?

Develop a framework that can accomodate observers in different decoherence contexts?

?

Failure of QM in certain regimes?

Deny absolute nature of observed events?

Abandon No Finetuning principle for causal discovery?

****One of the results of our paper:**

Relating Wigner's Friend scenarios to Nonclassical Causal Compatibility, Monogamy Relations, and Fine Tuning
arXiv: 2309.12987

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