Title: Relating Wigner's Friend Scenarios to Nonclassical Causal Compatibility, Monogamy Relations, and Fine Tuning

Speakers: Yìlè Yīng

Collection/Series: Causalworlds

Subject: Quantum Foundations, Quantum Information

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Relating Wigner's Friend Scenarios to Nonclassical Causal Compatibility, Monogamy Relations, and Fine Tuning

Yìlè Yīng

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with Marina Maciel Ansanelli, Andrea Di Biagio, Elie Wolfe, David Schmid, Eric Gama Cavalcanti

arXiv:2309.12987

Nonclassical Causal Models and Wigner's friend

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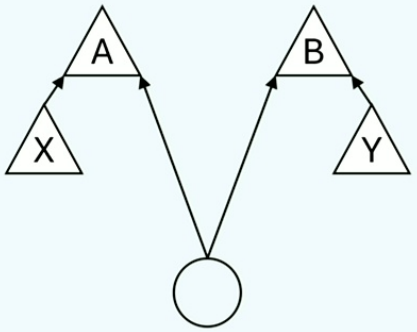
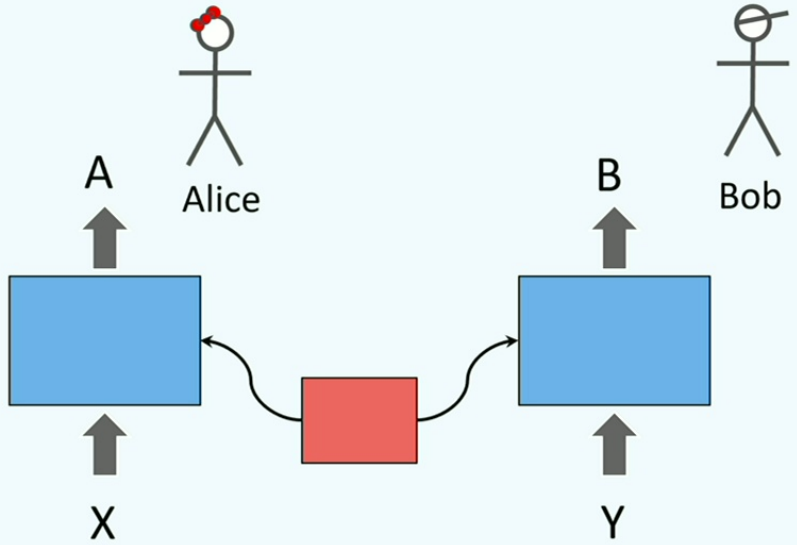
Classical causal models
and
Bell experiments

Causal structure:

- Directed Acyclic Graph (DAG)

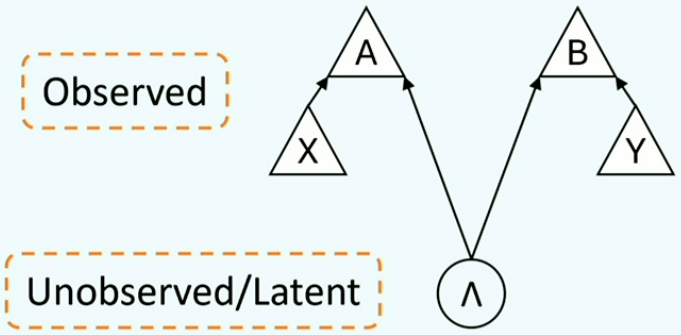




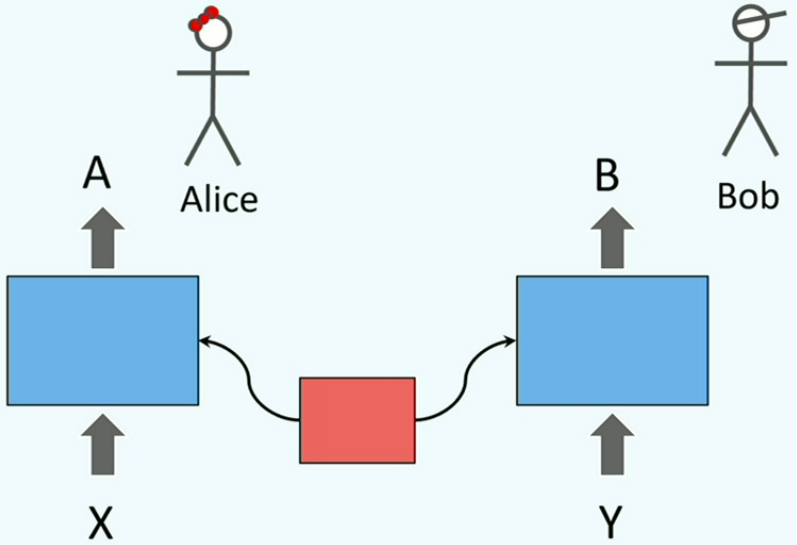
Classical Causal Models

Causal structure:

- Directed Acyclic Graph (DAG)

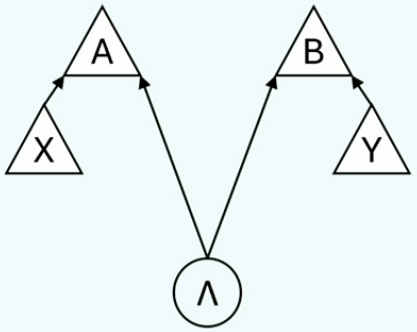


Classical random variable



Classical Causal Models

Causal structure:



Compatible probabilities:

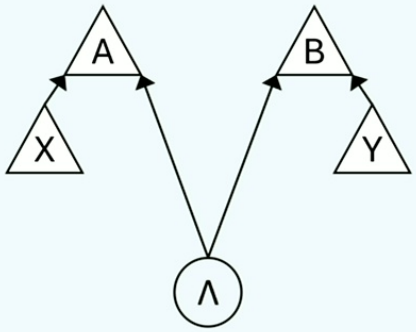
$$P(AB|XY) = \sum_{\Lambda} P(A|X\Lambda)P(B|Y\Lambda)P(\Lambda)$$

$$P(A|XY) = P(A|X)$$
$$P(B|XY) = P(B|Y)$$

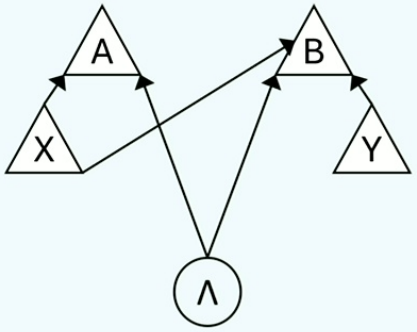
no superluminal signaling

Bell inequalities on P(AB|XY)

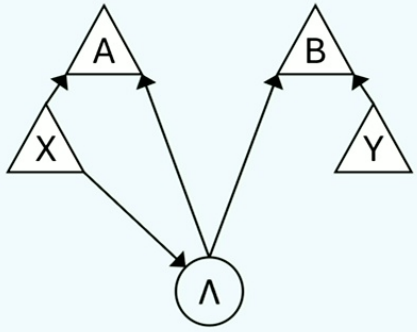
Any classical causal model with the Bell DAG cannot explain violations of Bell inequalities.



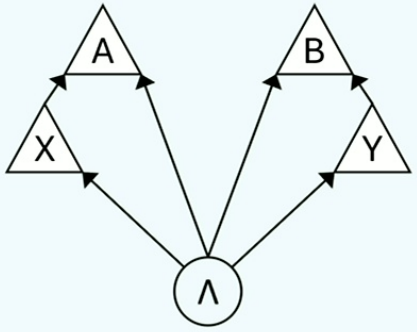
the Bell DAG



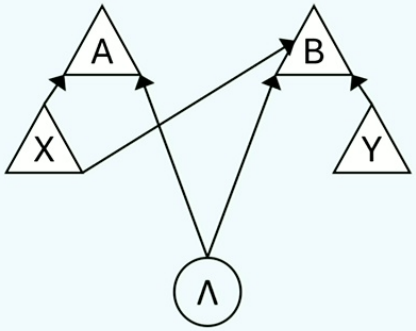
Superluminality

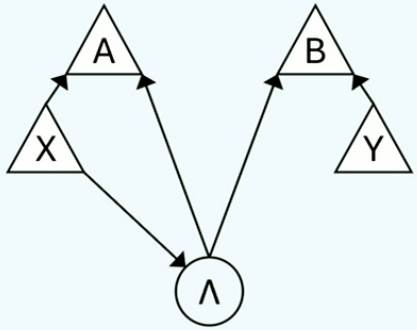


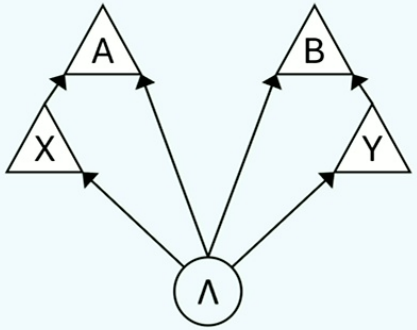
Retrocausality



Superdeterminism



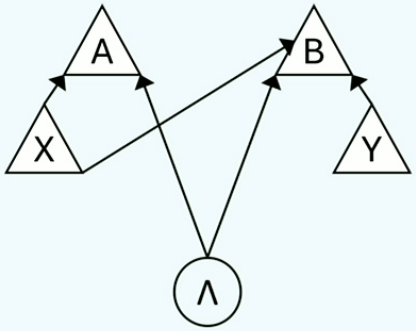


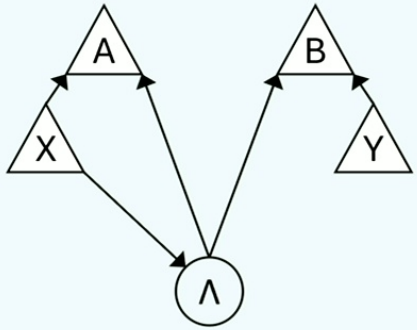


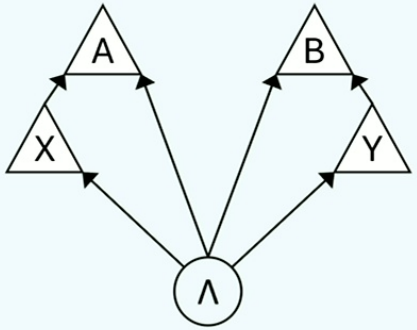
Need **fine-tuning** to explain no-superluminal-signaling

$$P(A|XY) = P(A|X)$$

$$P(B|XY) = P(B|Y)$$







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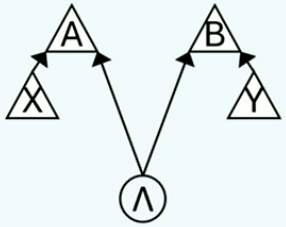
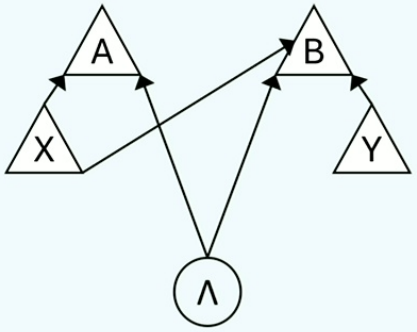


$$P(A|XY) = P(A|X)$$

$$P(B|XY) = P(B|Y)$$

C. J. Wood and R. W. Spekkens, arXiv:1208.4119

Problems with classical causal explanations



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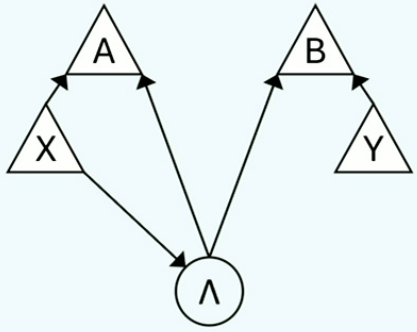
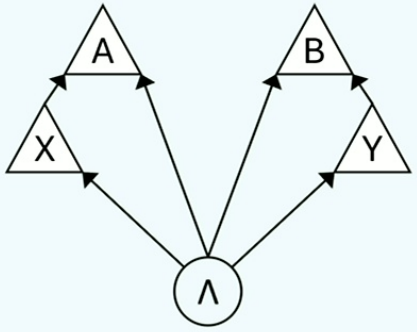


Retrocausality



Superdeterminism

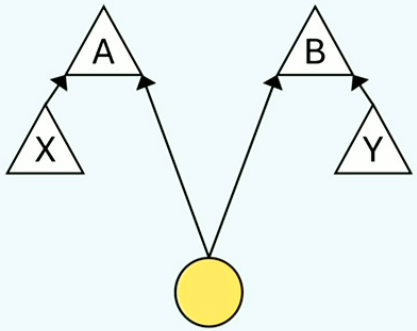
Need **fine-tuning** to explain no-superluminal-signaling

Nonclassical causal models

Keep the causal structure intact
Generalize the notion of causality

Nonclassical Causal Models

Causal structure:



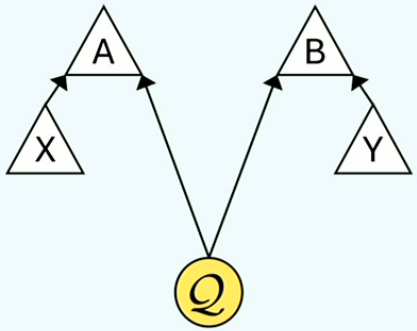
Compatible probabilities

$$P(AB|XY) = \sum_{\Lambda} P(A|X\Lambda)P(B|Y\Lambda)P(\Lambda)$$

Bell inequalities on P(AB|XY)

Quantum Causal Models

Causal structure:



Compatible probabilities

$$P(AB|XY) = \sum_{\Lambda} P(A|X\Lambda)P(B|Y\Lambda)P(\Lambda)$$

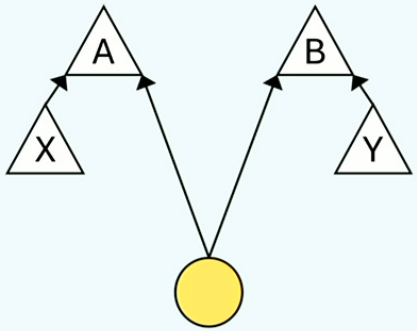
Quantum bound on P(AB|XY)

(e.g., Tsirelson's bound for CHSH)

Generalized Probabilistic Theory (can be classical, quantum, or beyond-quantum)

GPT Causal Models

Causal structure:



Compatible probabilities

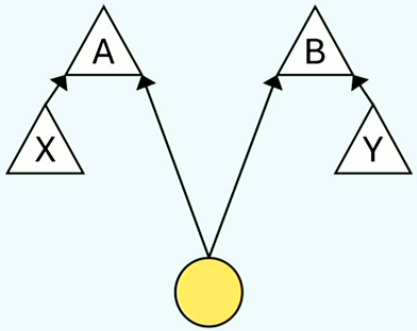
$$P(AB|XY) = \sum_\Lambda P(A|X\Lambda)P(B|Y\Lambda)P(\Lambda)$$

No-superluminal-signaling bound on P(AB|XY)

Generalized Probabilistic Theory (can be classical, quantum, or beyond-quantum)

GPT Causal Models

Causal structure:



Compatible probabilities

Independence constraints on observed nodes

$$P(A|XY) = P(A|X)$$

$$P(B|XY) = P(B|Y)$$

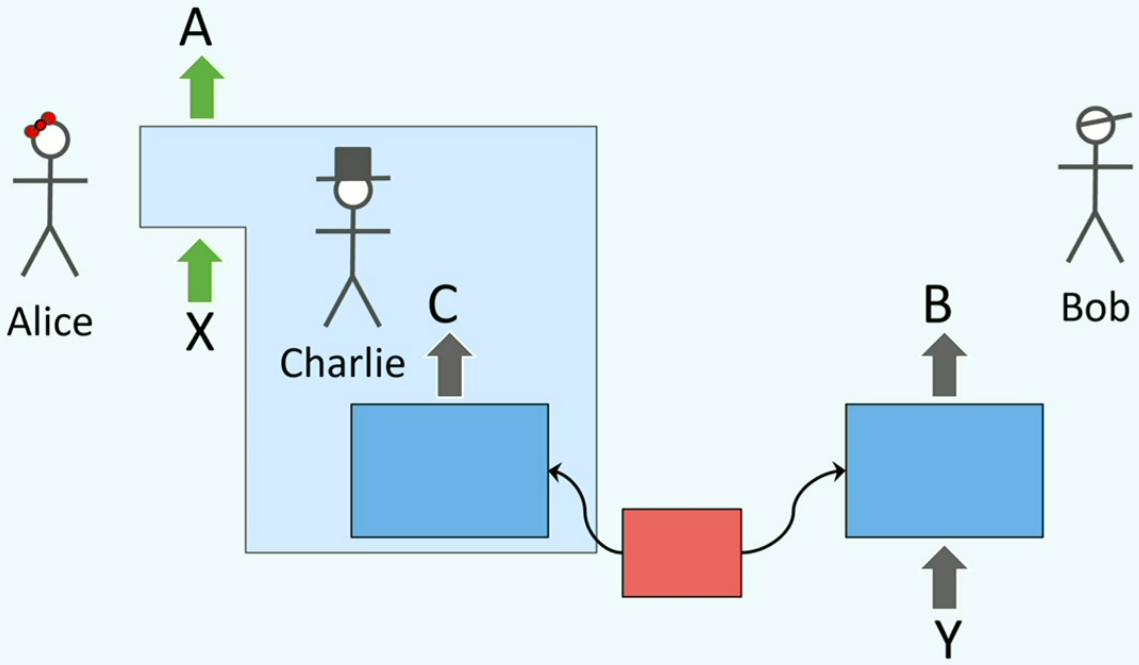
No-superluminal-signaling bound on P(AB|XY)

J. Henson, R. Lal, and M. F. Pusey [arXiv:1405.2572]

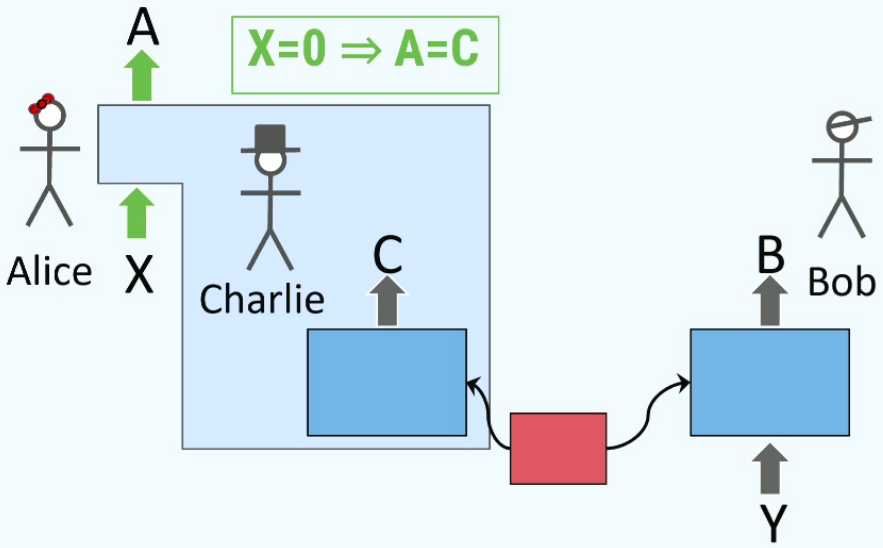
However…here comes Wigner's friend

D. Schmid, Y. Yīng, and M. Leifer,
A review and analysis of six extended *Wigner's friend arguments,* [arXiv:2308.16220]

Local Friendliness (LF) experiment

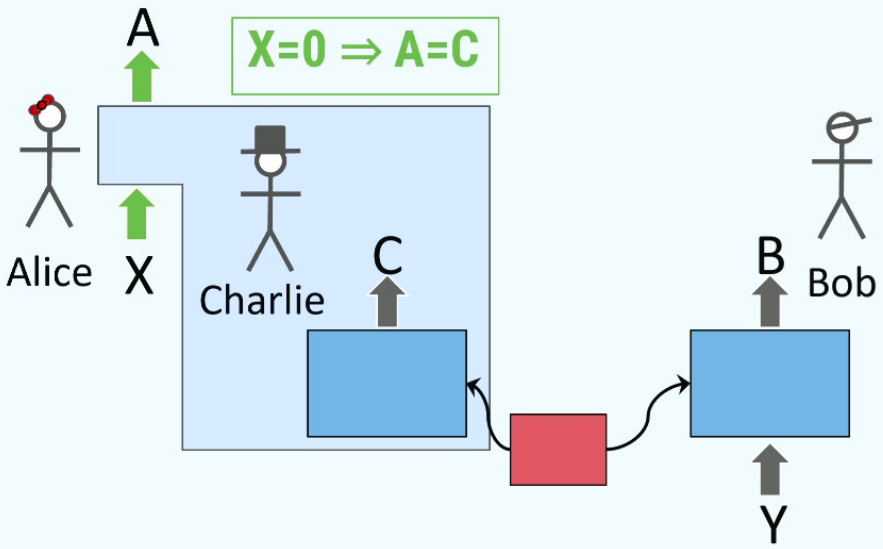


Bong et al, [arXiv:1907.05607]; Wiseman, Cavalcanti and Rieffel, [arXiv:2209.08491]



Monogamy relations!

P(AB|XY) and P(AC|XY) constrain each other



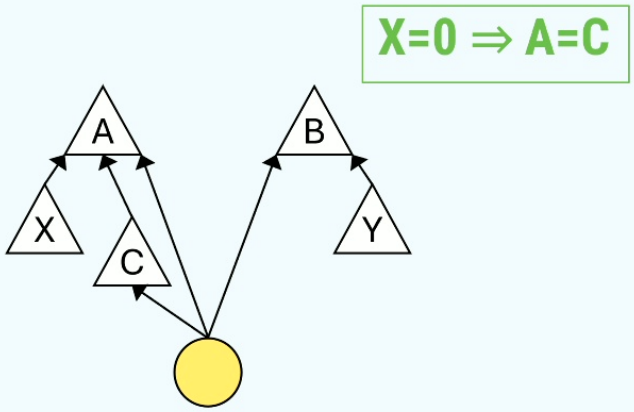
Monogamy relations!

P(AB|XY) and P(AC|XY) constrain each other

Local Friendliness (LF) inequalities on P(AB|XY)

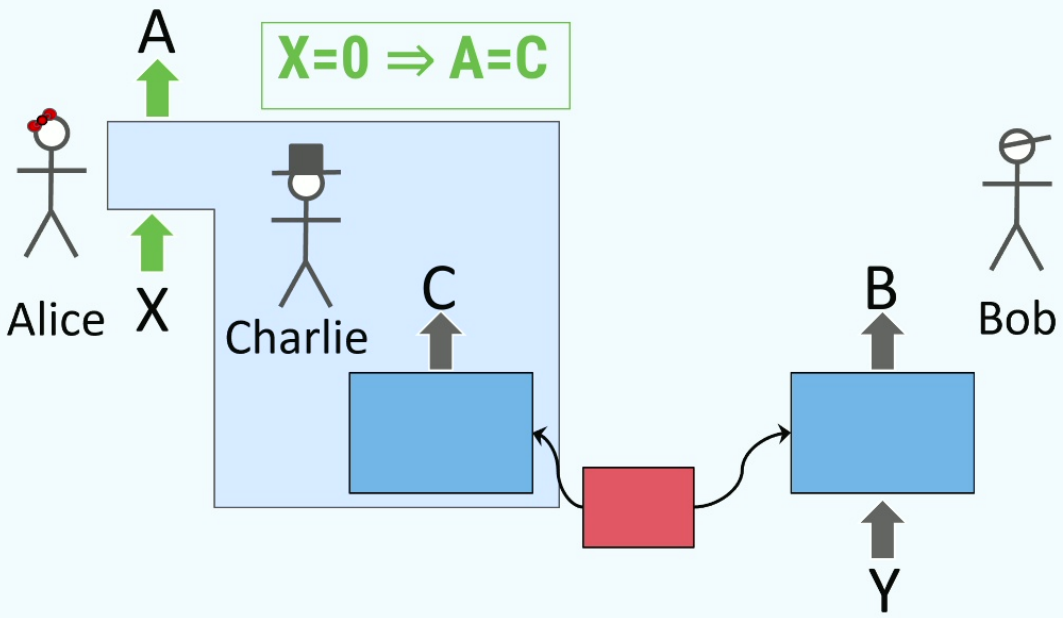
weaker than Bell inequalities in general

Any GPT causal model with the LF DAG cannot explain violations of Local Friendliness inequalities!



the LF DAG

Quantum violations of LF inequalities



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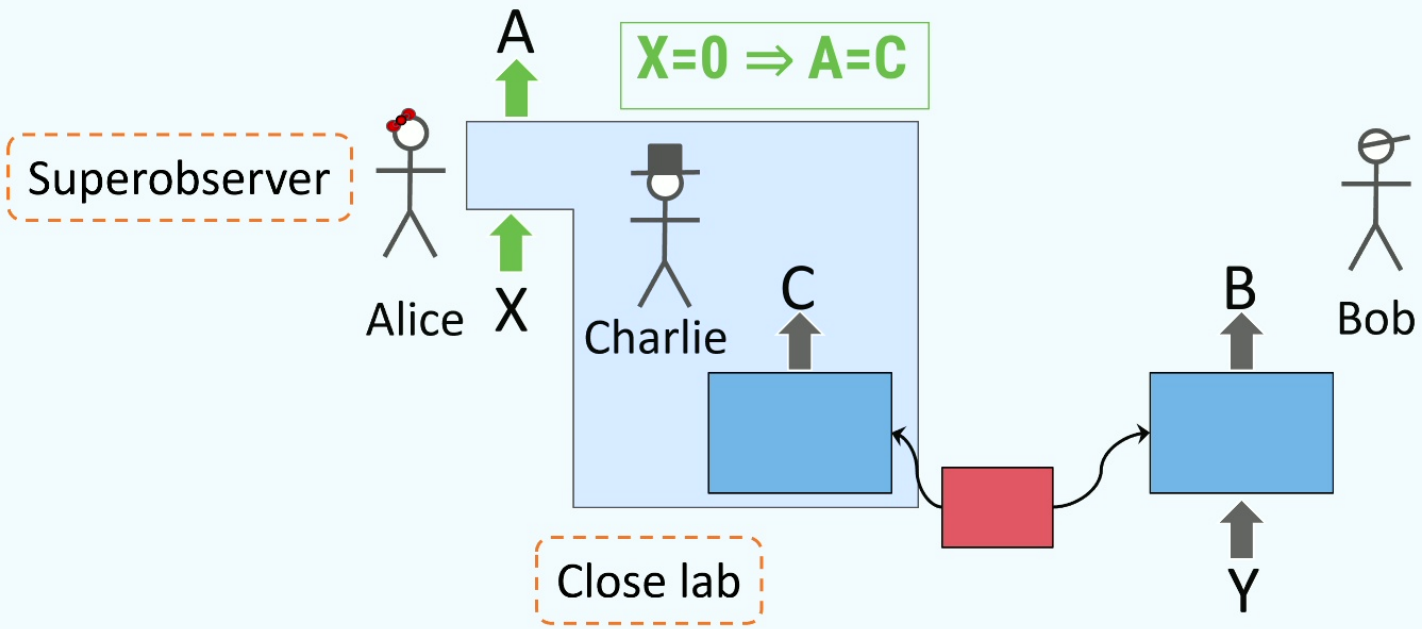

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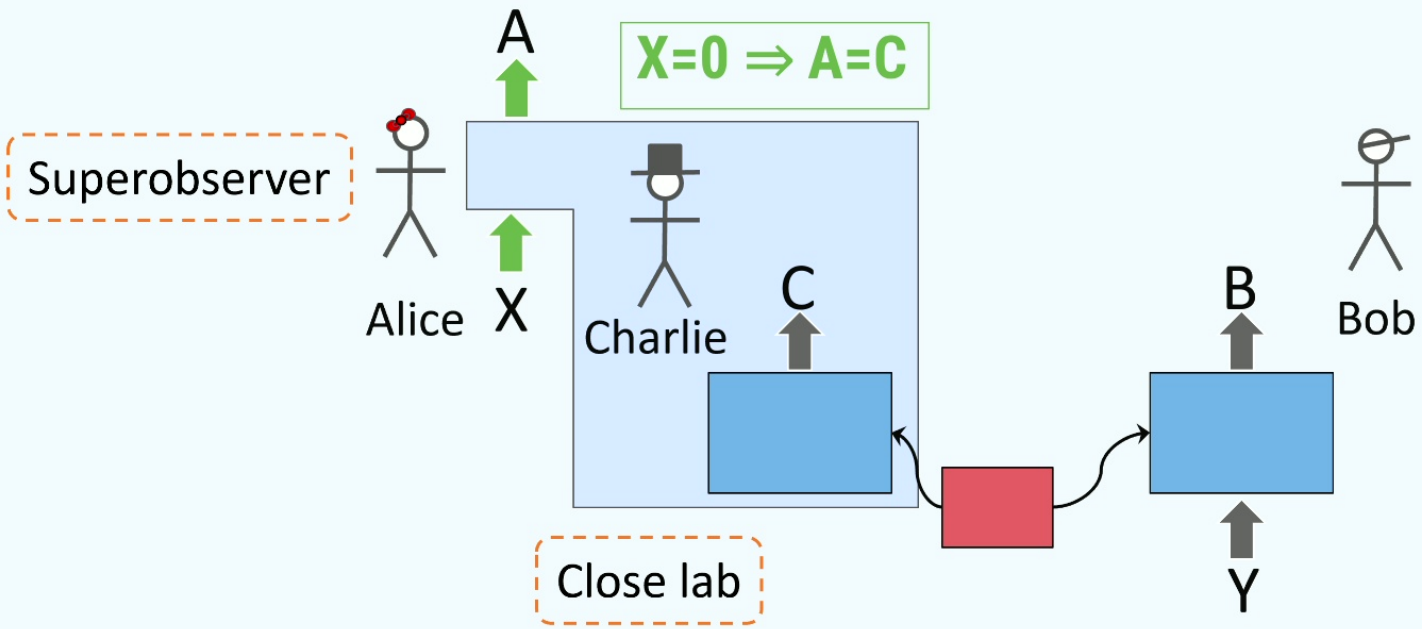

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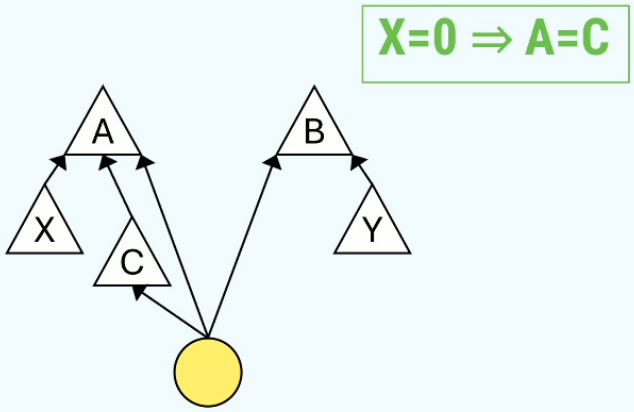
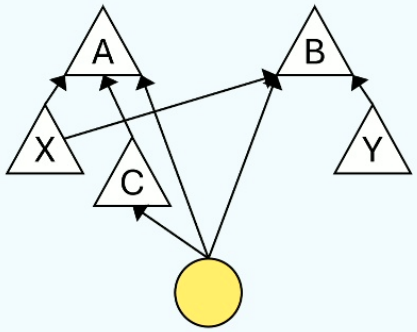
Any GPT causal model with the LF DAG cannot explain violations of Local Friendliness inequalities!



the LF DAG

Problems with GPT causal explanations



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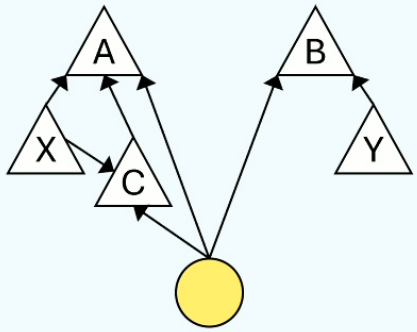
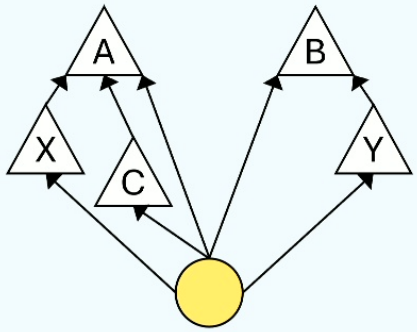
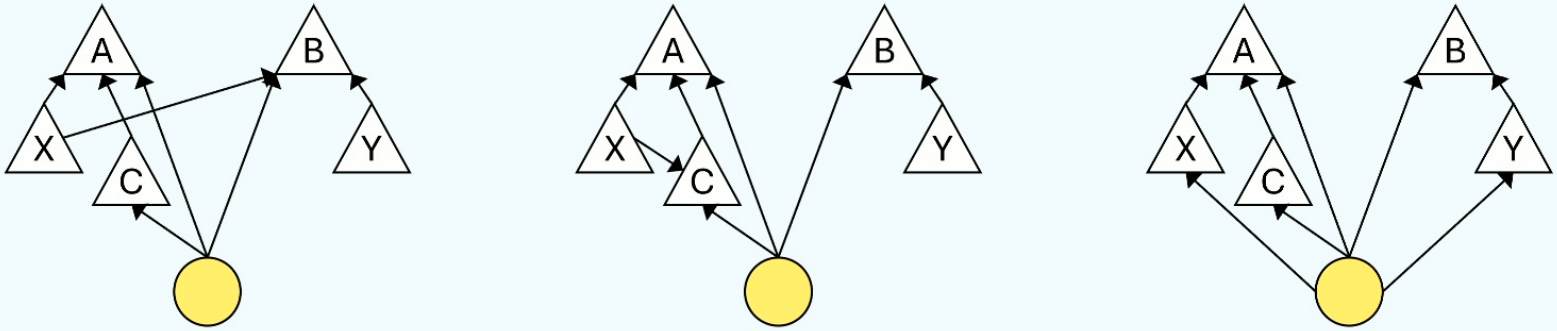


Retrocausality



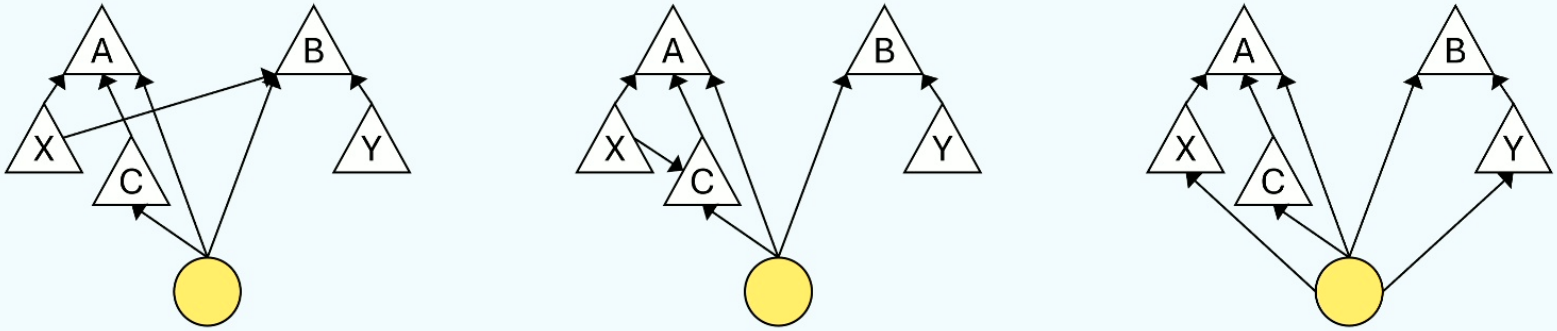
Superdeterminism

Problems with GPT causal explanations



Need **fine-tuning** to explain no-superluminal/retro-signaling!

Problems with GPT causal explanations



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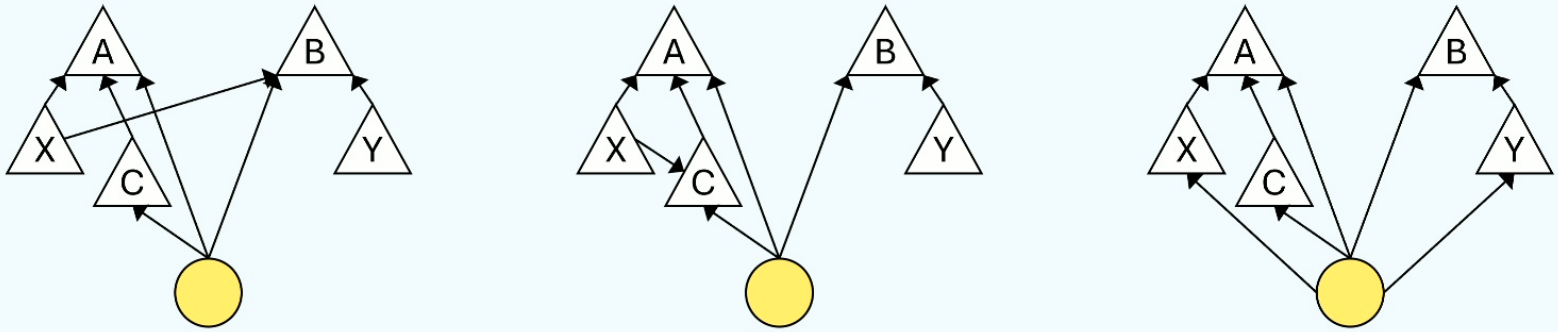

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$$P(C|XY) = P(C)$$

We are sent back to the conundrum we had earlier!

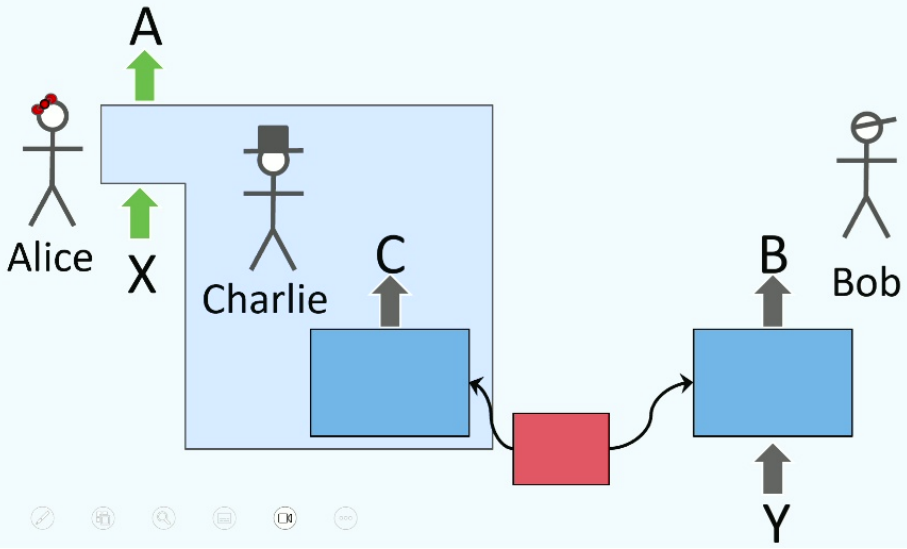
We can explain Bell inequality violations by invoking a quantum common cause in the Bell DAG.

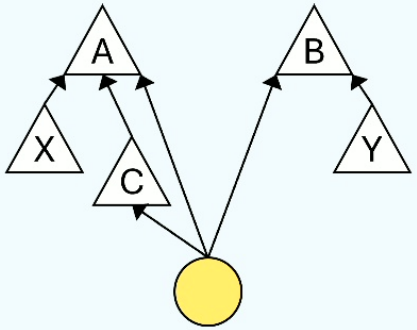
But ***NO*** quantum, GPT (or certain even-more-exotic) causal models with the LF DAG can explain any violation of LF inequalities.

Explaining by modifying the LF DAG (including making it cyclic) ***always*** leads to ***fine-tuning*** and **contradictions** with crucial causal principles.

The Local Friendliness experiment poses a much ***stronger*** *challenge to causal modeling than Bell's experiment.*

The existence of the joint distribution P(ABCXY)





the LF DAG

The existence of the joint distribution P(ABCXY)

Absoluteness of Observed Events (AOE):

Any observed event is single, definite and absolute; it is not relative to anything or anyone.

→ a random variable for Charlie's **outcome** (even if its **record** may be erased)

- Arguably implicitly assumed in Bell's and other theorems in physics/biology…
- AOE **can** coexist with the assumption of unitary quantum dynamics

  Unlike the collapse postulate, AOE is **not** about dynamics

  e.g., in the de Broglie-Bohm (pilot-wave) theory

  - A key innovation of ***extended*** Wigner's friend theorems: no collapse postulate
- Rejected by Many-worlds, Relational Quantum Mechanics, QBism, etc.

V. Vilasini, M. Woods, [arXiv:2209.09281] N. Ormrod, J. Barrett, [arXiv:2401.18005]

Thanks! :)

yying@pitp.ca

D. Schmid, Y. Yīng, and M. Leifer, [arXiv:2308.16220]

A review and analysis of six extended Wigner's friend arguments