Quantum-Classical Gaps in Causal Inference

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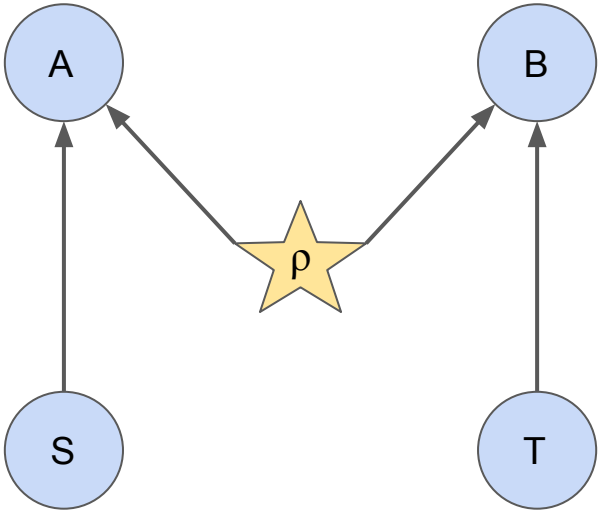
Robert Spekkens, Elie Wolfe, Thomas (TC) Fraser, Marina Maciel Ansanelli

Credits for figures to Marina

Drawing the line between **classical** and **quantum**

Bell experiment:



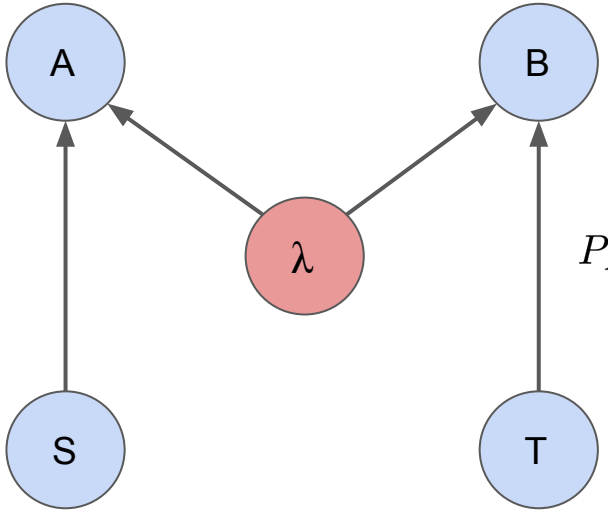
ρ is a quantum system

DAG = Directed Acyclic Graph

$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$$

C.J. Wood and R.W. Spekkens: arxiv 1208.4119 (2015)

Directed Acyclic Graphs



Find probability distributions (P) compatible with the DAG

$$P_{\mathrm{ABST}}(a,b,s,t) = \sum_{\lambda} P_{\mathrm{A|S},\lambda}(a|s,\lambda) P_{\mathrm{B|T},\lambda}(b|t,\lambda) P_{\mathrm{S}}(s) P_{\mathrm{T}}(t) P_{\lambda}(\lambda)$$

$$P_{\mathrm{ABST}}(a,b,s,t) = \mathrm{Tr}\left[(M_{\mathrm{AS}} \otimes M_{\mathrm{BT}})\rho_{\mathrm{AB}}\right]$$

Framework: **causal inference**

1. Correlation ≠ causation
2. Common cause principle
3. Induced correlation

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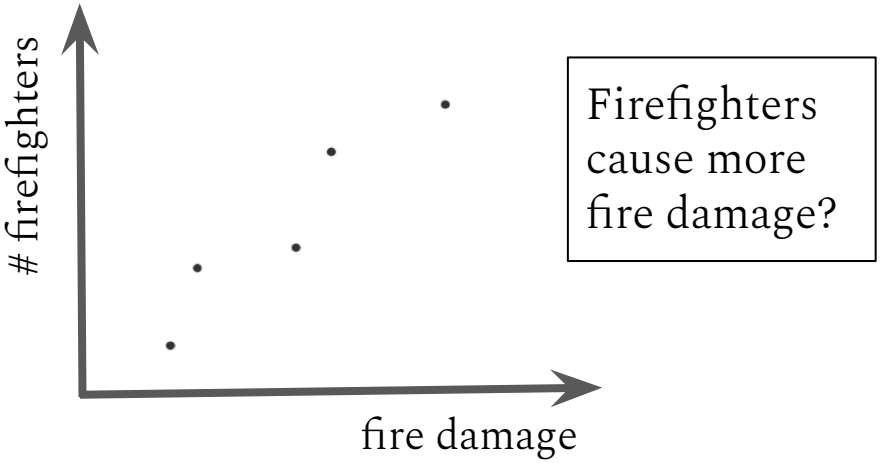
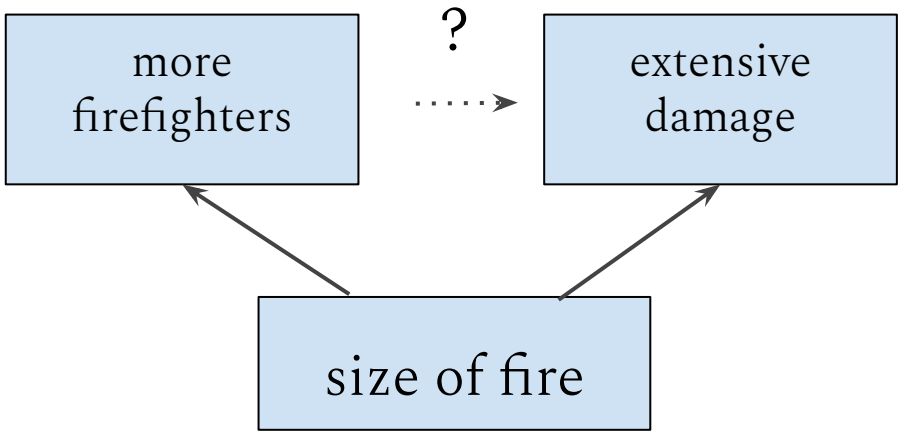
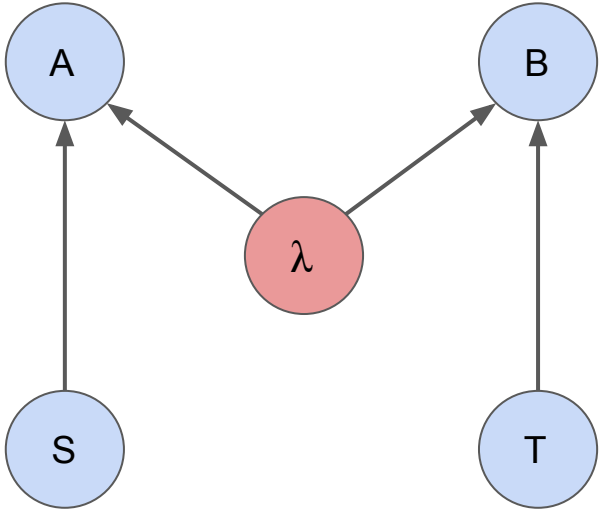
1. Correlation ≠ causation



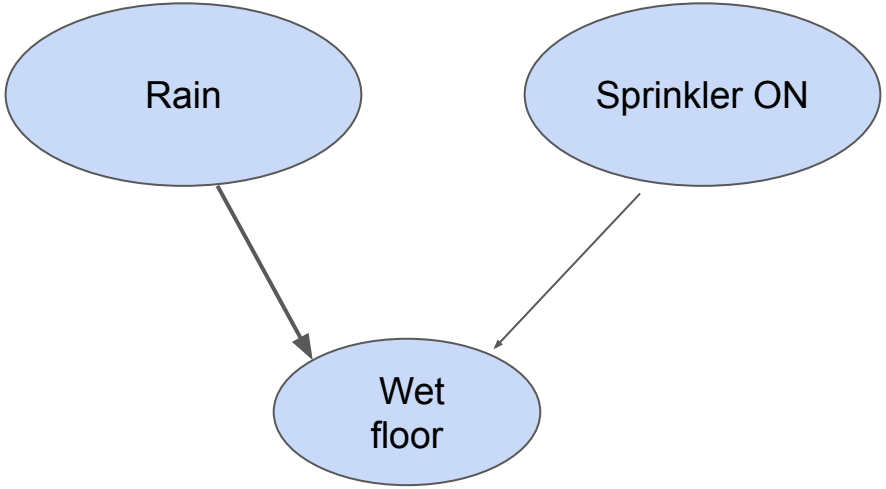


Having a larger fire is a common cause

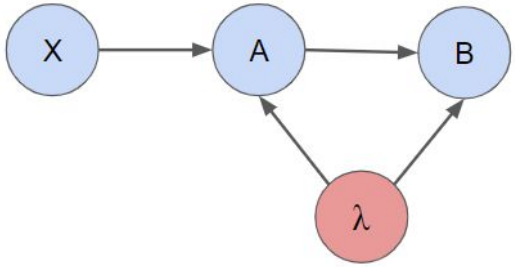
2. Common cause principle



3. Induced correlation

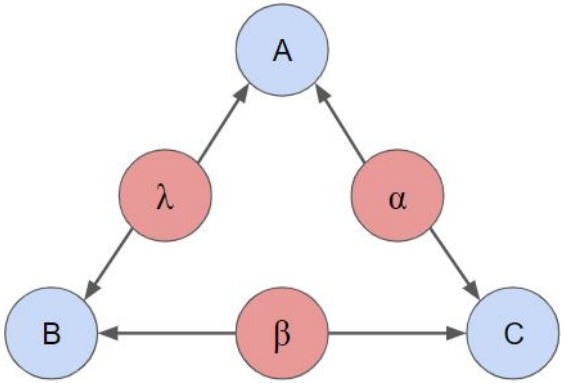


Other structures that have **QC-gap**



Instrumental Scenario

T. Van Himbeeck et.al.: arxiv 1804.04119 (2019)

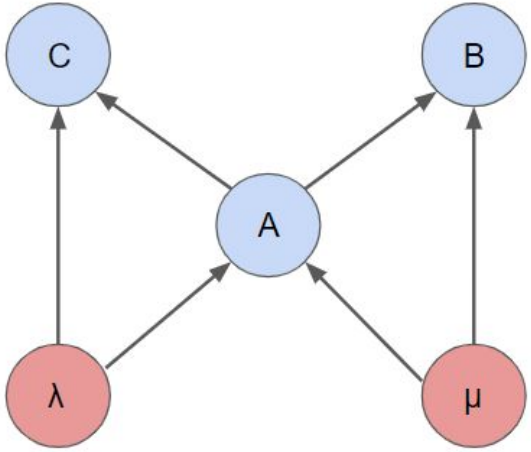


Triangle Scenario

E. Wolfe et.al. : arxiv 1909.10519 (2021)

etc...

Many of them we **don't know**

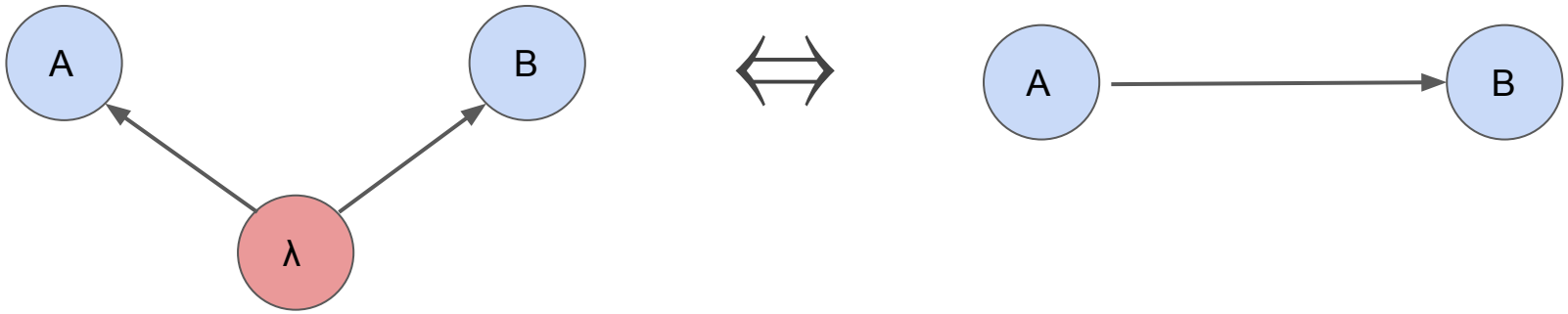


Evans scenario

Methods for finding QC-gaps

1. Observational equivalence
2. Fritz method
3. Marginalisation
4. Conditioning

1. Observational equivalence



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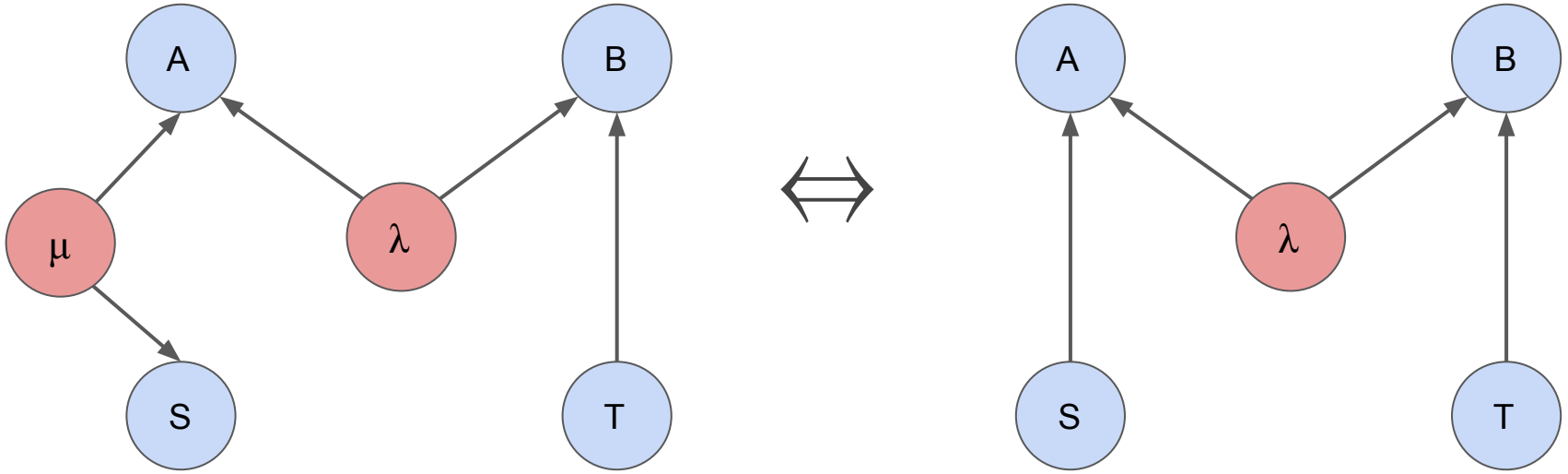
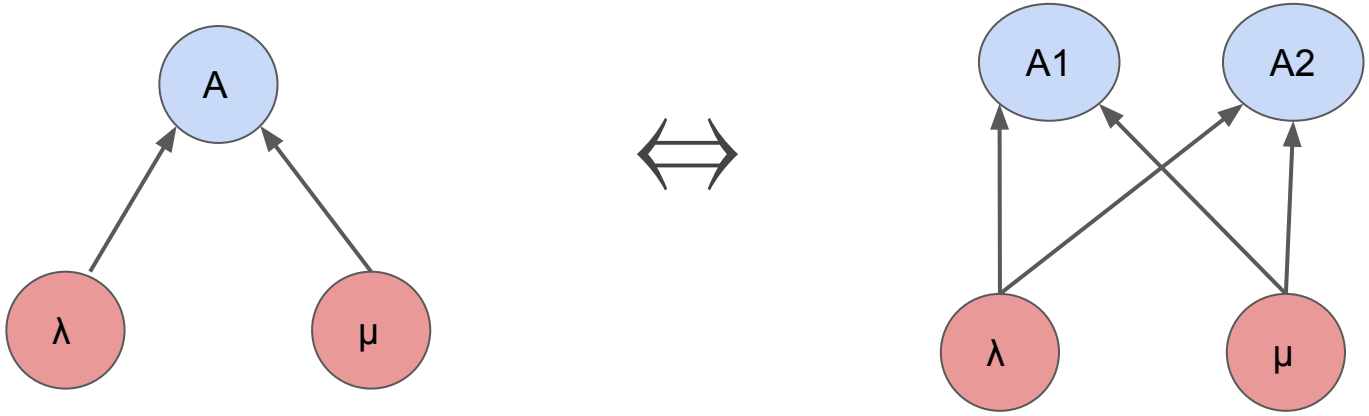
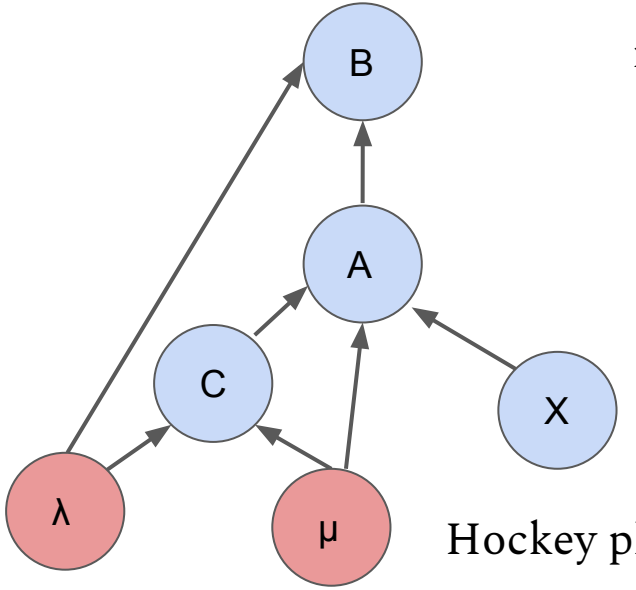


2. Fritz trick



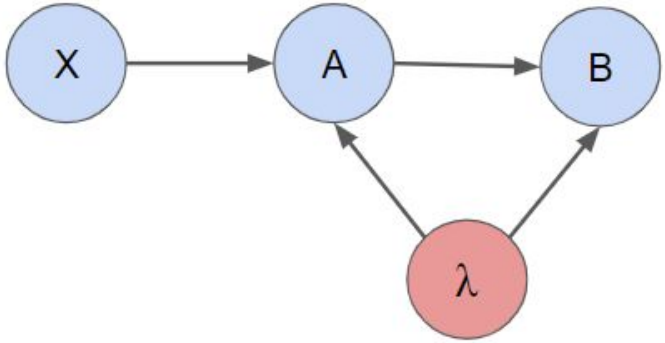
3. Marginalisation

Quantum caveat : teleportation (avoid cloning)



Hockey player

marginalise over C



Instrumental

4. Conditioning

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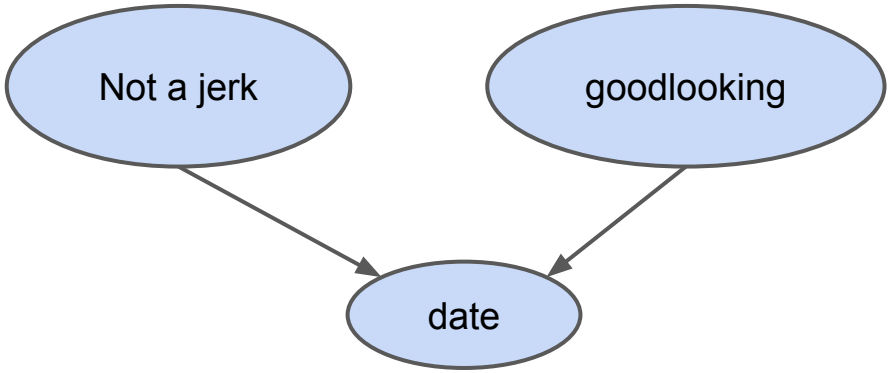
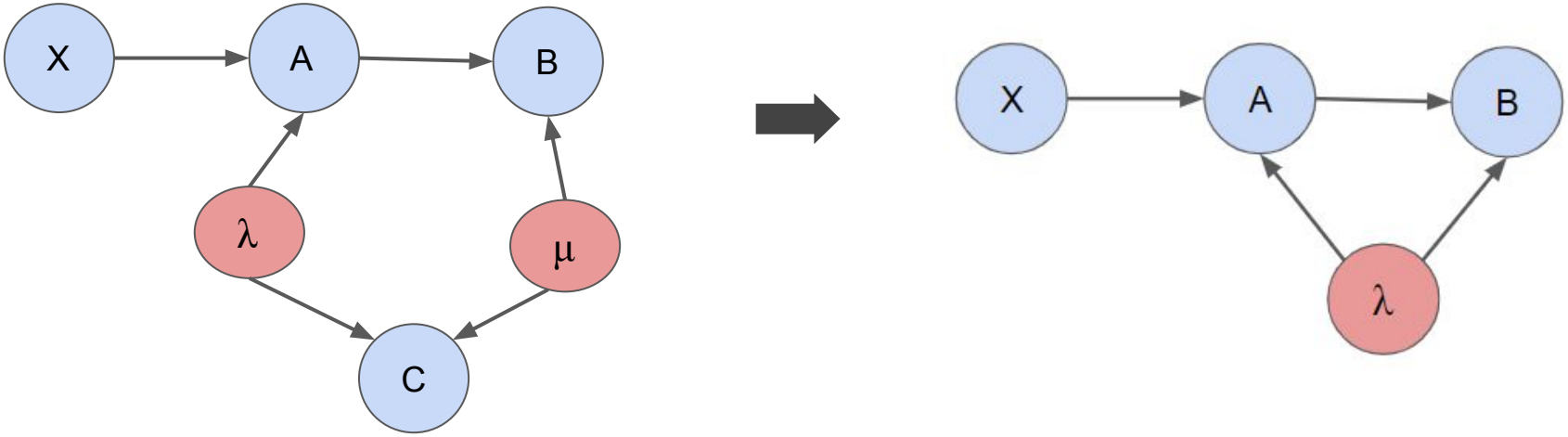


4. Conditioning



Results

- New QC-gaps
- Improved framework and formalism

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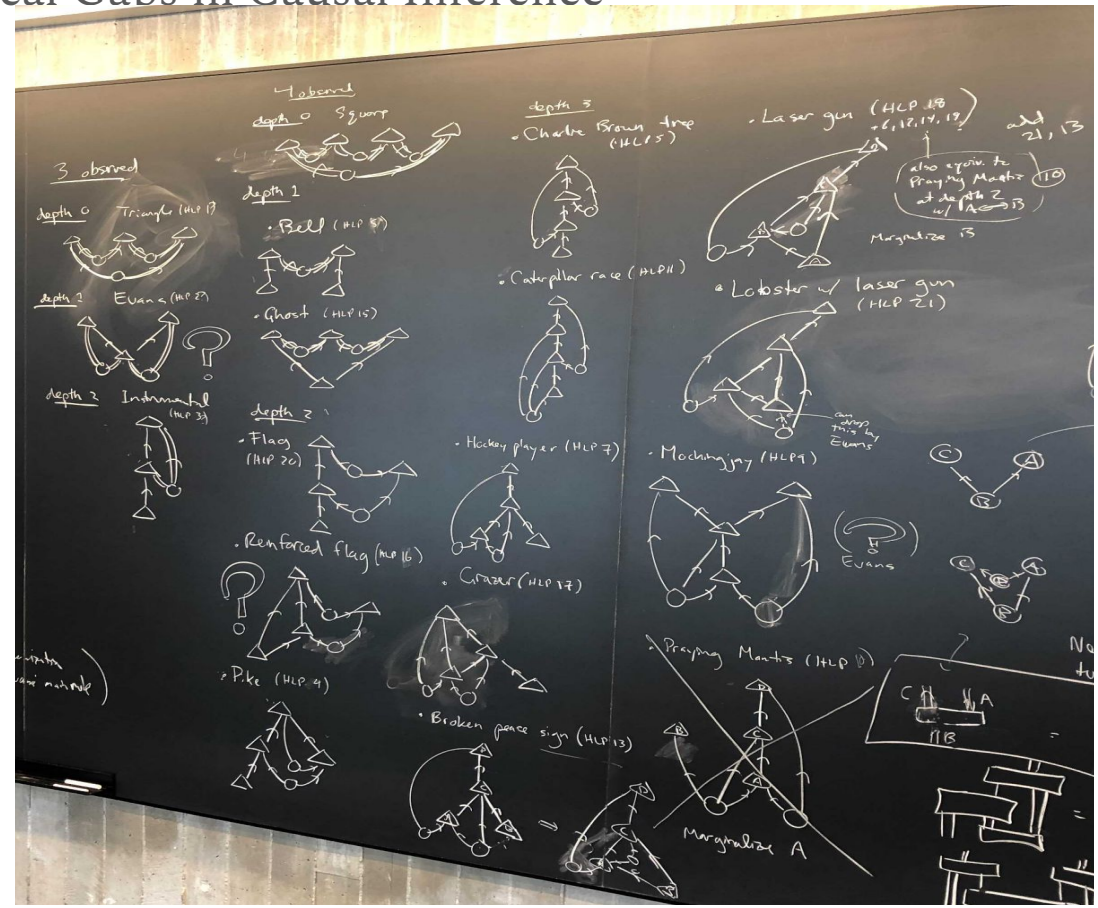

HLP, 2014

Why were the PSIons happy despite not finding a QC-gap in Evans scenario?

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They thought maybe they would get a **No-Bell prize**...