Title: Beyond local causality: causation and correlation after Bell

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Abstract: There is now a remarkable mathematical theory of causation. But applying this theory to a Bell scenario implies the Bell inequalities, which are violated in experiment. We alleviate this tension by translating the basic definitions of the theory into the framework of generalised probabilistic theories. We find that a surprising number of results carry over: the d-separation criterion for conditional independence (the no-signalling principle on steroids), and even certain quantitative limits on correlations. Finally, we begin a classification of the causal structures, such as the Bell scenarios, that are "interesting" from this perspective. Joint work with Joe Henson and Raymond Lal.

The steps in Bell's theorem

Some words

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$$\Downarrow$$

$$p(a,b|x,y) = \int_\Lambda p(a|x,\lambda)p(b|y,\lambda)p(\lambda)d\lambda$$

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Bell inequalities

The steps in Bell's theorem

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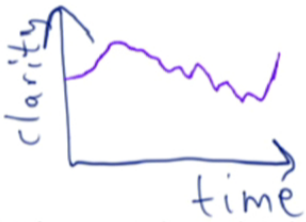

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$$p(a,b|x,y) = \int_\Lambda p(a|x,\lambda)p(b|y,\lambda)p(\lambda)d\lambda$$

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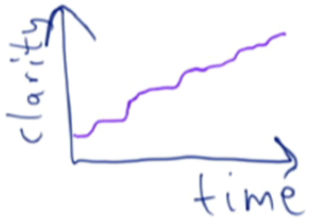


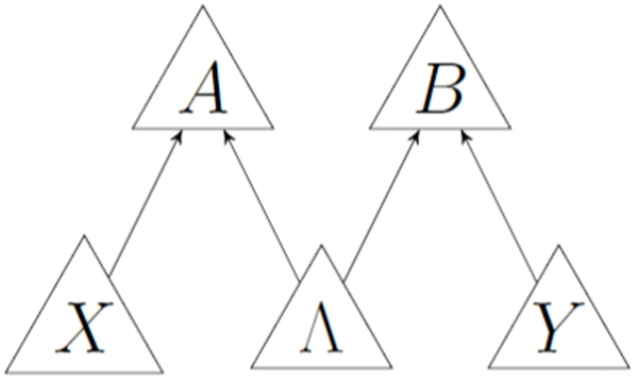
Bell inequalities

$$\Downarrow$$

Cool stuff

A DAG paints a thousand words

1. This is the DAG:



Outline

1. A more general interpretation of DAGs using generalised probabilistic theories.

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2. Generalisation of d-separation criterion for conditional independence.
3. Qualitative limits on correlations (even in arbitrary non-classical theories).

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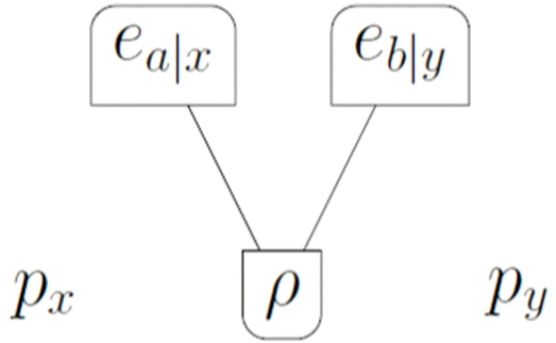
2. Generalisation of d-separation criterion for conditional independence.
3. Qualitative limits on correlations (even in arbitrary non-classical theories).
4. Progress in classifying "interesting" DAGs.

Example

$$p(a, b, x, y) =$$



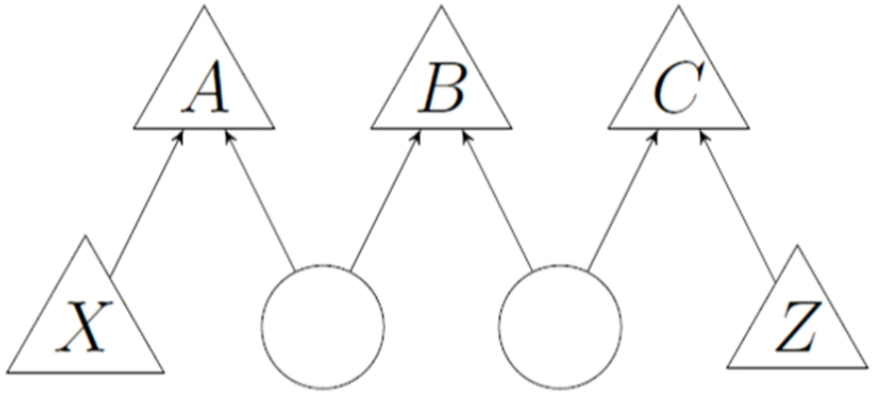
[$\{e_{a|x}\}_a$ and $\{e_{b|y}\}_b$ are tests for all x, y]

Example

$$p(a,b,x,y) = \mathrm{Tr}\left((E_{a|x} \otimes E_{b|y})\rho\right) p(x)p(y)$$

$[\{E_{a|x}\}_a$ and $\{E_{b|y}\}_b$ are POVMs for all $x, y]$

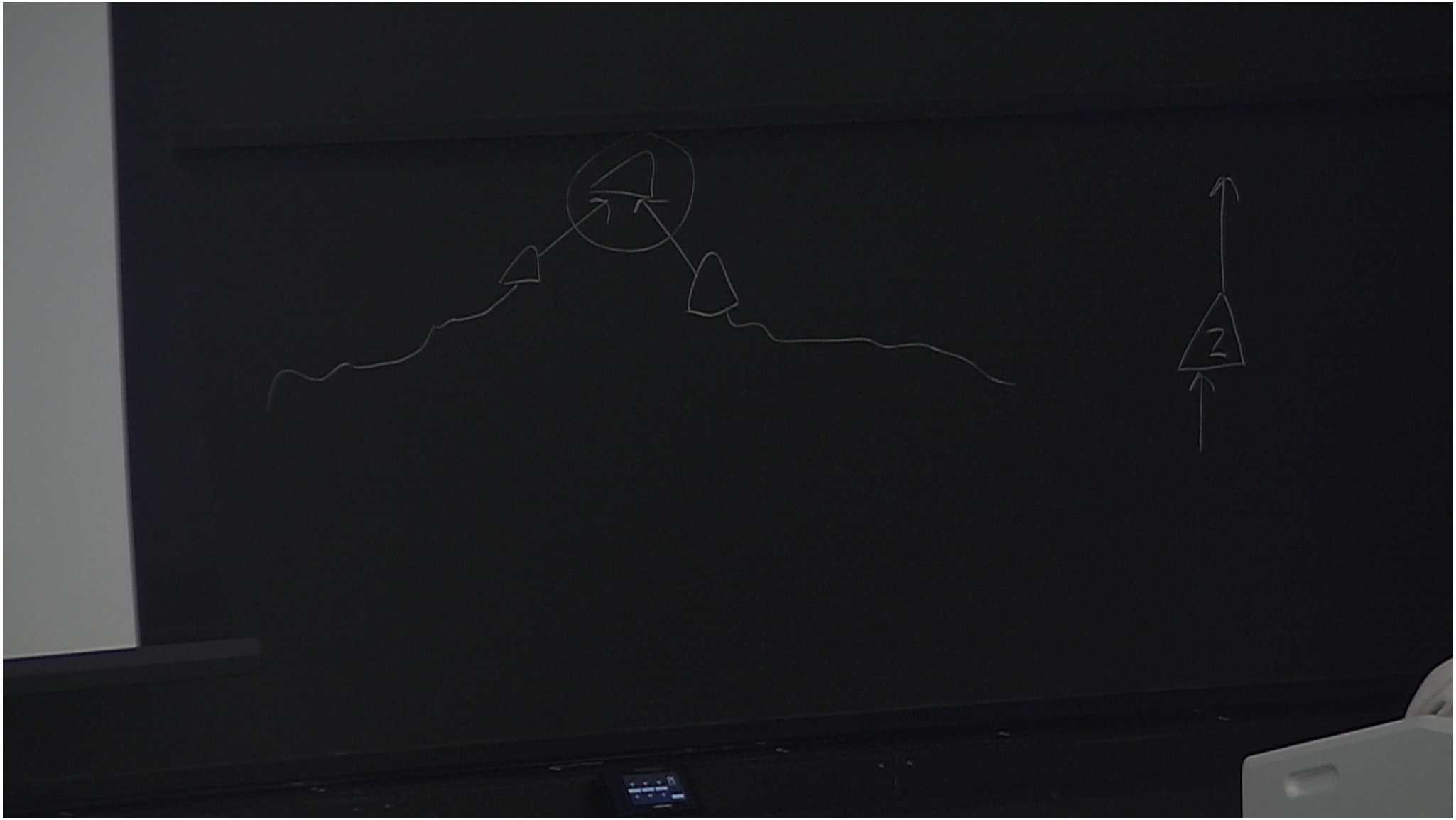
Example: Bi-locality



d-separation

A path is *blocked* by Z if:

- it passes head-to-head through a node that is not in Z, and whose descendants are not in Z, or
- it passes, not head-to-head, through a node in Z.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d-separation

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X is *d-separated* from Y by Z if every path from X to Y is blocked by Z.

“Interesting” DAGs, size 6