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Crosstalk and causal graphs

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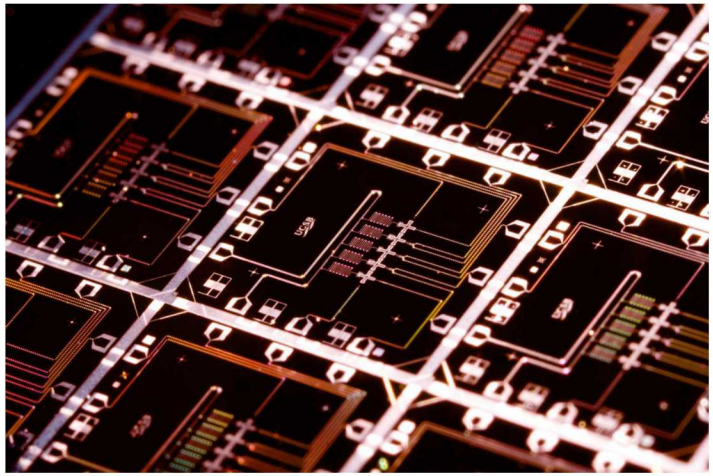
Crosstalk: an emergent class of errors



Martinis, UCSB & Google

Crosstalk can come from:

1. Poor electromagnetic shielding in control lines
2. Always-on interactions or unwanted interactions
3. Photon scatter
4. Measurement post-processing
5. …

A critical error mode for most quantum computing architectures – can violate *error locality* assumptions behind fault tolerance.

Diagnosing and mitigating crosstalk

1. **<u>Detect</u> crosstalk**
   - A binary answer, for any subset of qubits.

2. **<u>Quantify</u> crosstalk**
   - Talk about the amount crosstalk (not distinguishing between the different types)

3. **<u>Characterize</u> crosstalk**
   - Identify the type of crosstalk one has, quantify its degree, perhaps even write down its exact form

Increasing information,

Increasing degree of difficulty

Increasing complexity of protocols

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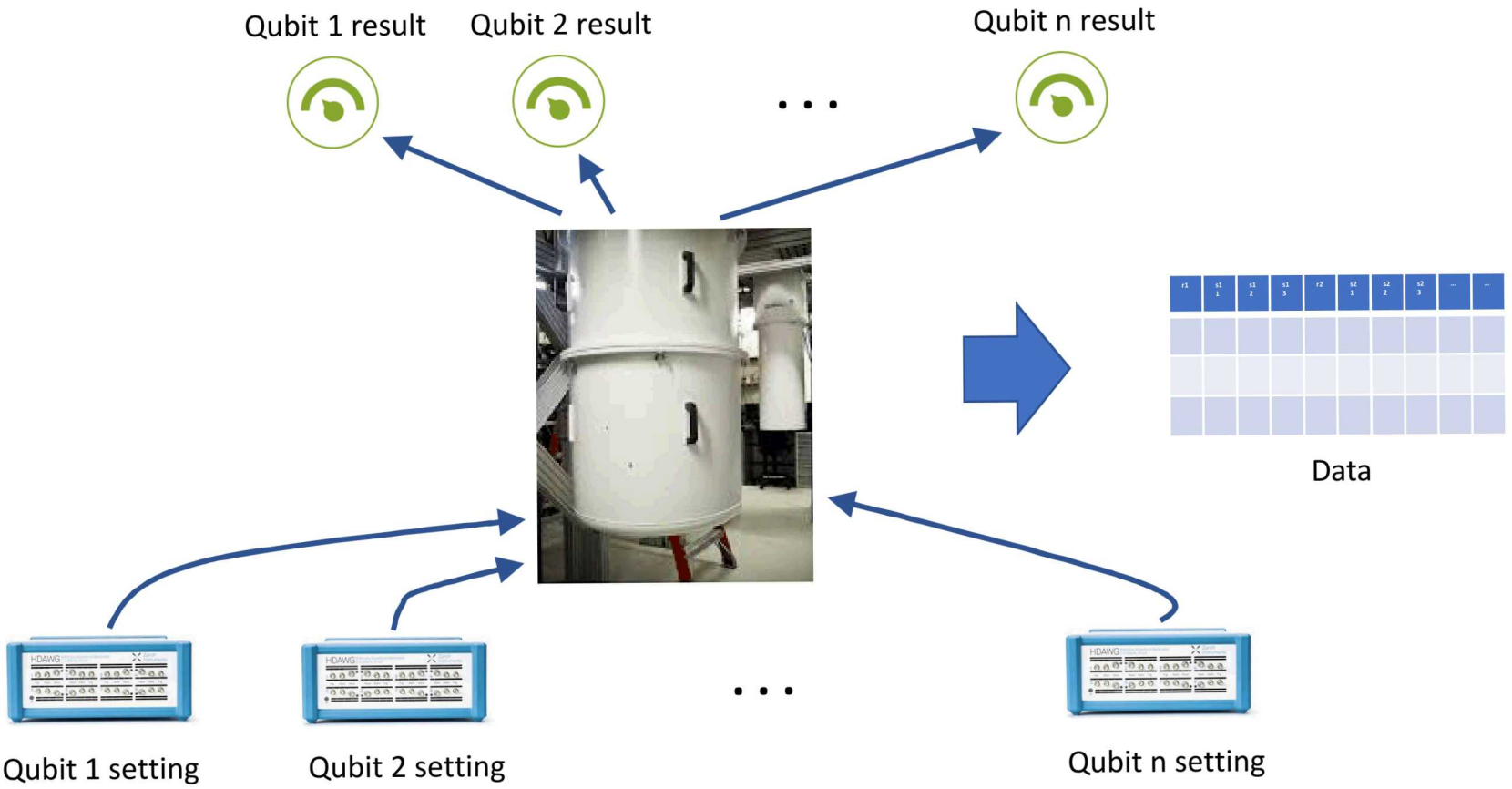
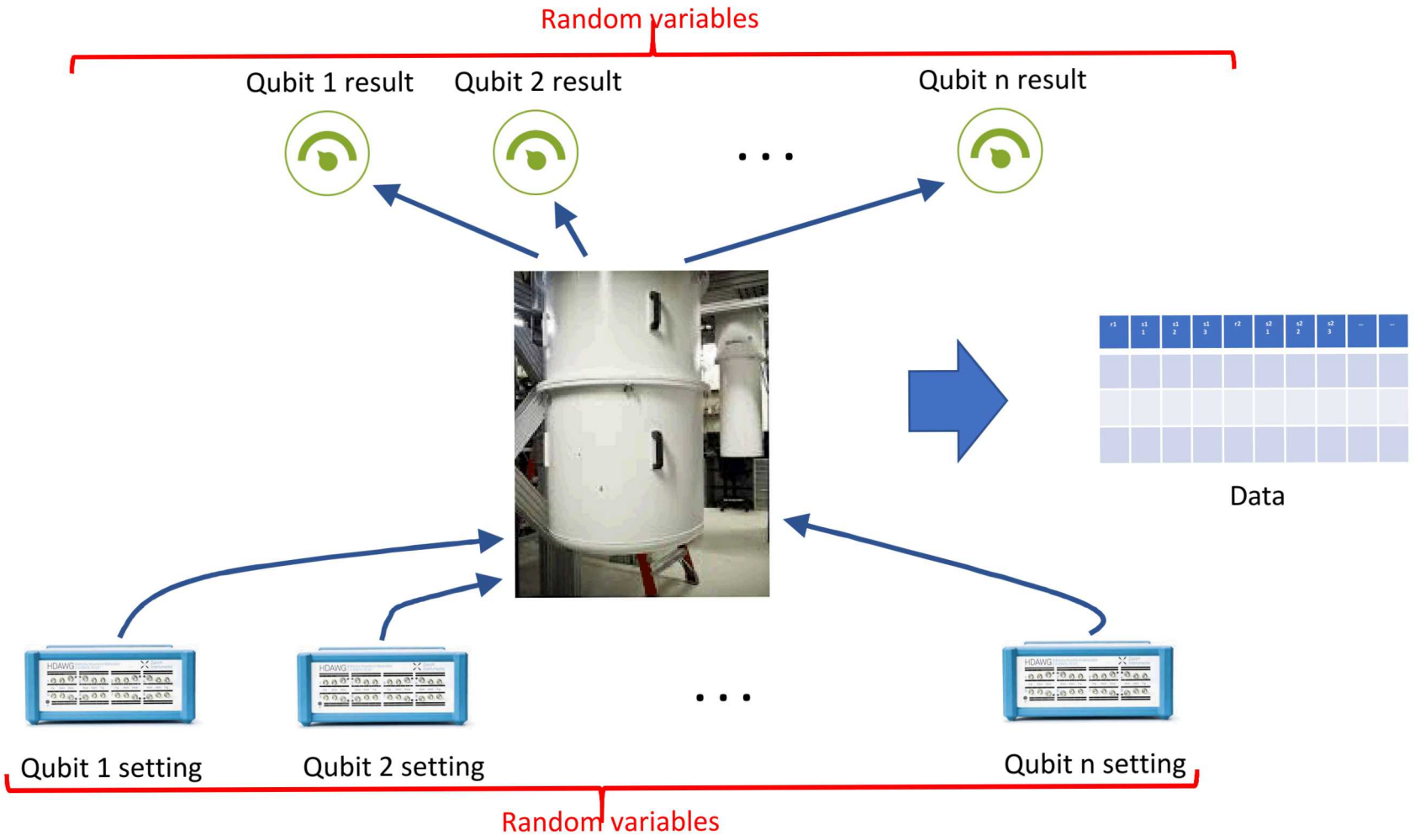
- A tool for crosstalk diagnosis: causal graph estimation
  - Light-weight
  - Black-box – makes no assumptions or estimates of internal physics
  - Can only detect and quantify
  - Can pick up all kinds of crosstalk (but doesn't distinguish between them)

Causal graph estimation

Crosstalk : the view from the lab



Formalizing the view from the lab



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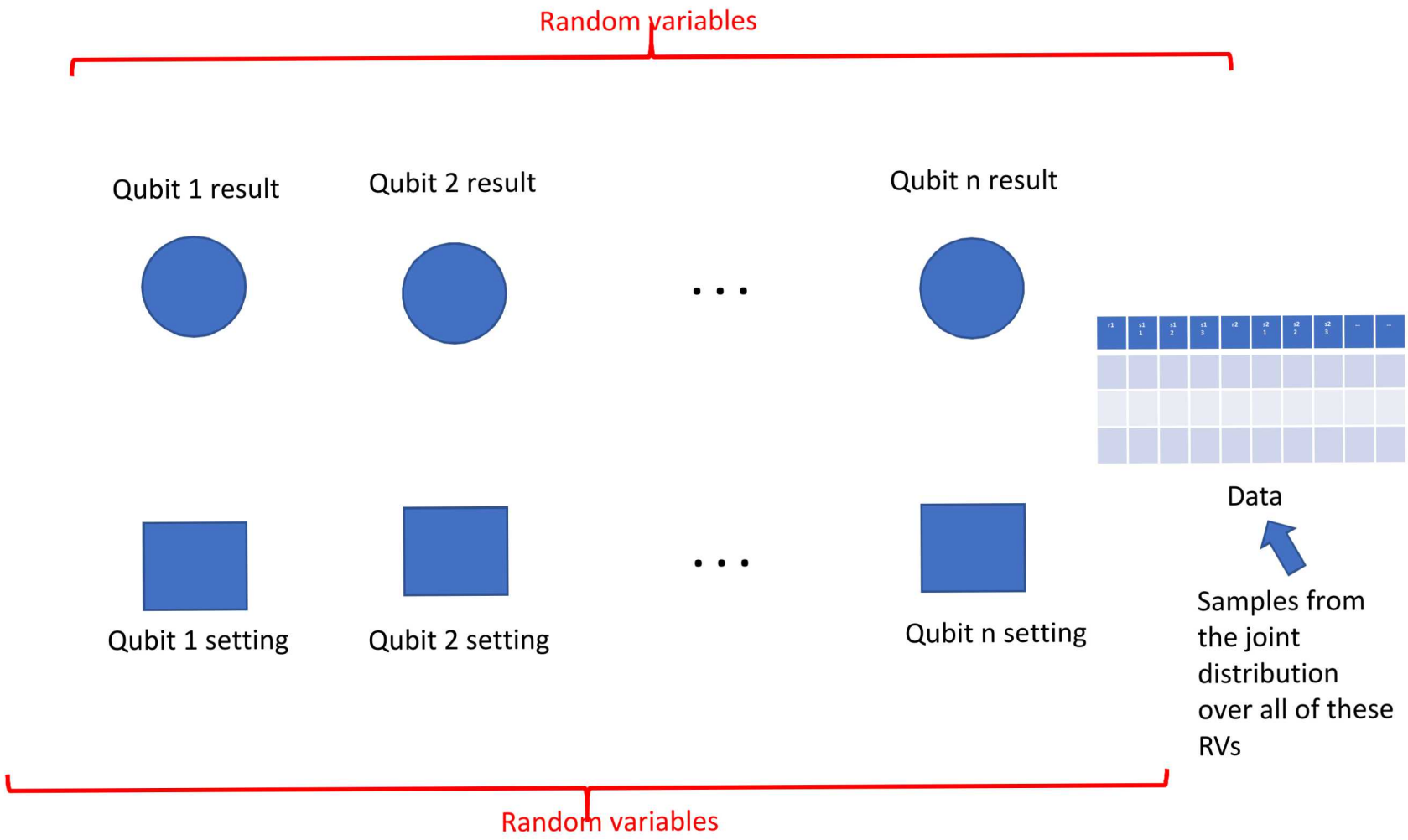

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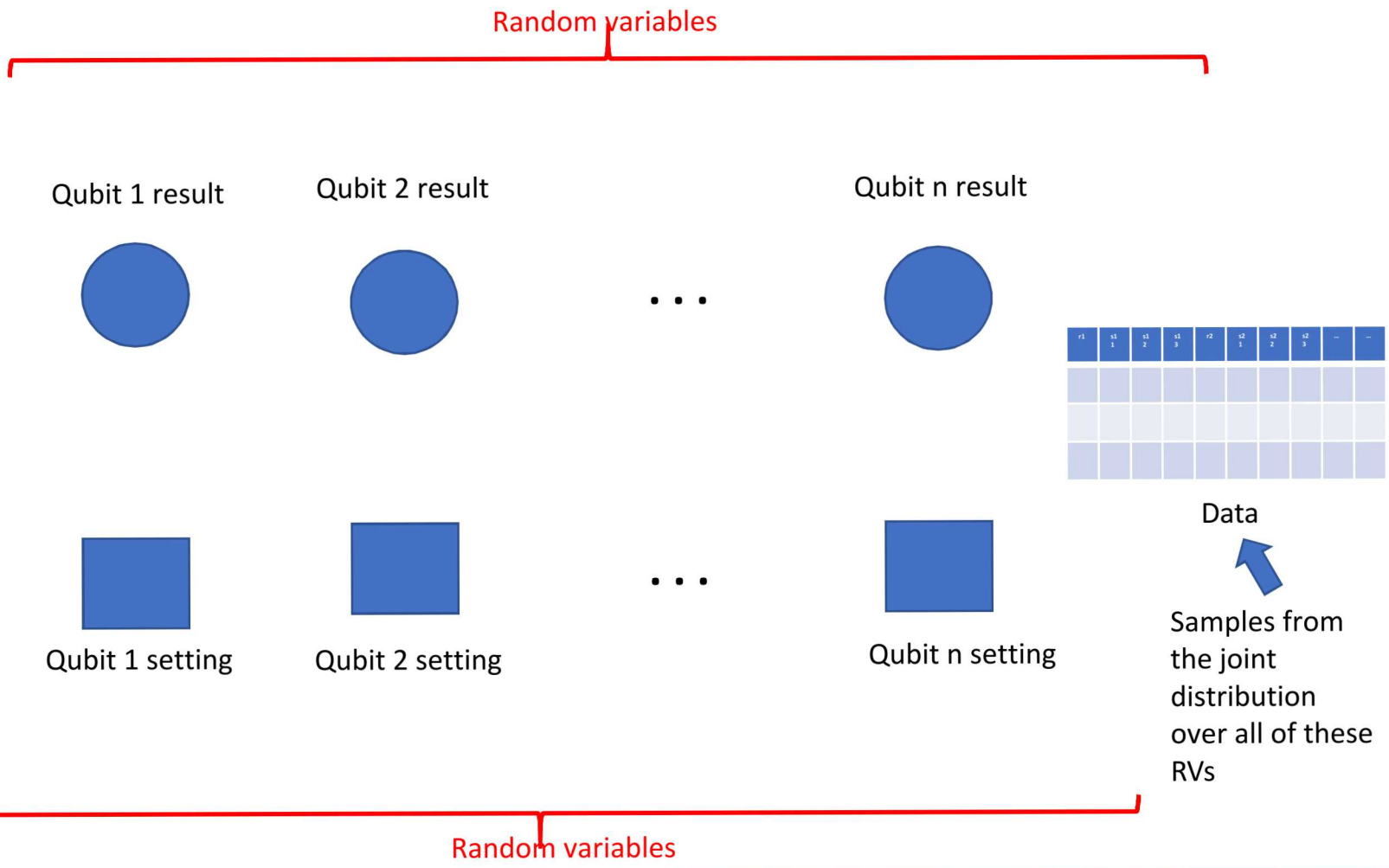


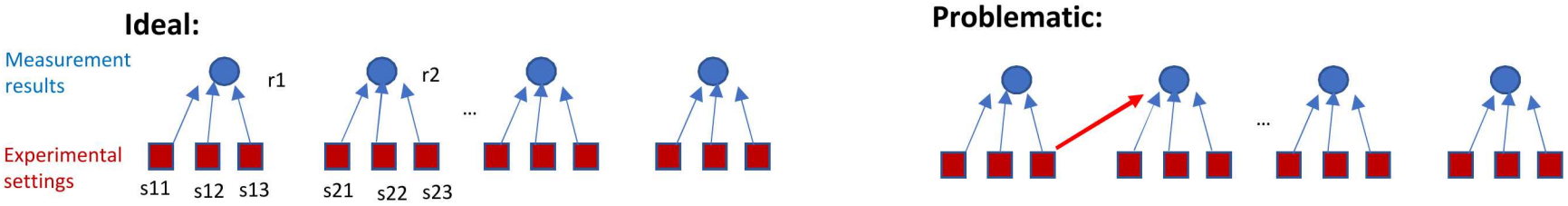
The absence of crosstalk is:

$$X_{\text{result } i} \perp (X_{\text{result } j}, X_{\text{setting } j}) \mid X_{\text{setting } i}$$

These relationships can be verified using statistical tests on the data

The causal graph for multi-qubit experiments

- Nodes are random variables
- edges indicate causal relationships (*conditional dependency*) between variables

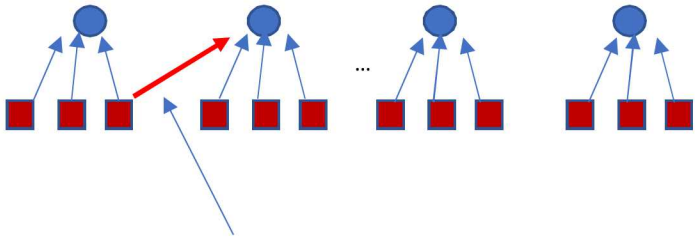


Need two ingredients to construct such graphs from data

1. **A statistical test for conditional independence**
   e.g. G2 (log likelihood ratio) test

2. **A graph discovery algorithm that tests and prunes edges efficiently**
   e.g. the PC algorithm [Sprites & Glymour, 2000]

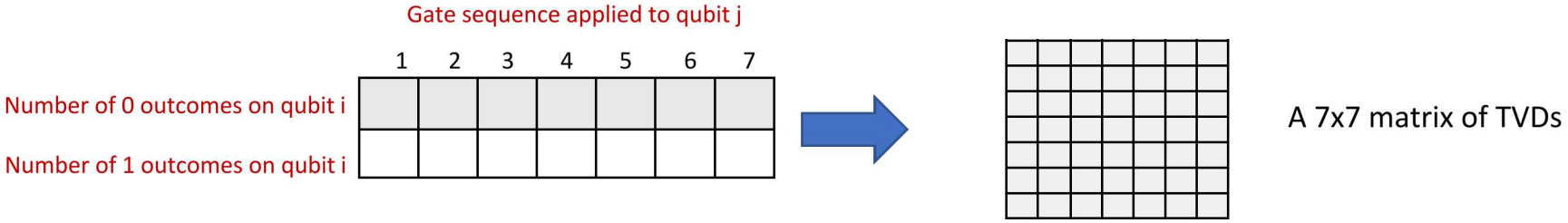
Quantifying crosstalk



How “much” crosstalk does this represent?

Can quantify how much the probability distribution of the dependent variable varies as the source variable is changed.

Same as context dependence quantification, except here the source variable can take several values and therefore we get a matrix of variations.



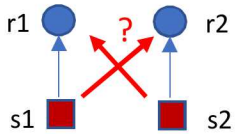
A 7x7 matrix of TVDs

We take the **maximum variation** as the measure of crosstalk.

Implementation and simulations

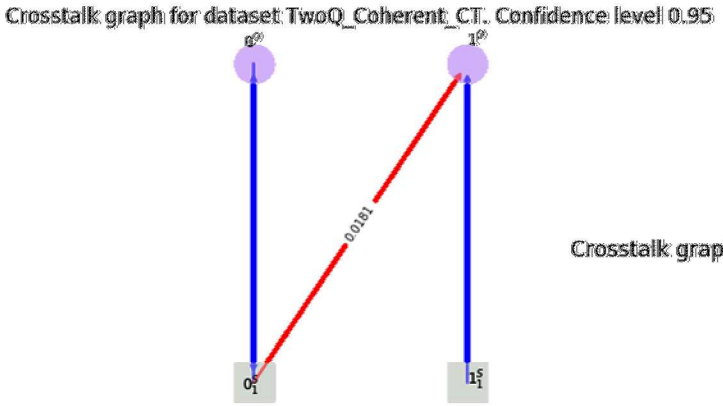
Have implemented code in PyGSTi to perform this crosstalk detection and quantification (develop branch).

- We'll use the simplest test case with two qubits, and only one setting per qubit:

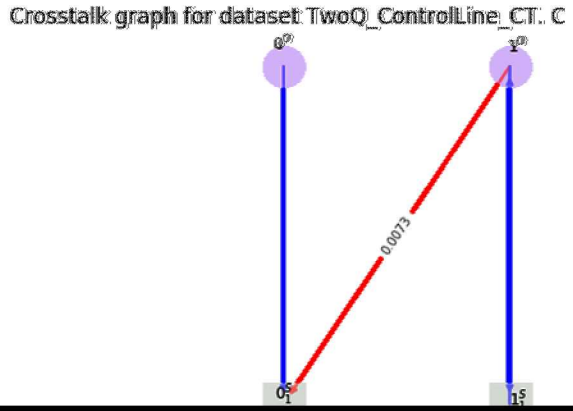


- This setting will enumerate the GST gate sequence applied to that qubit.

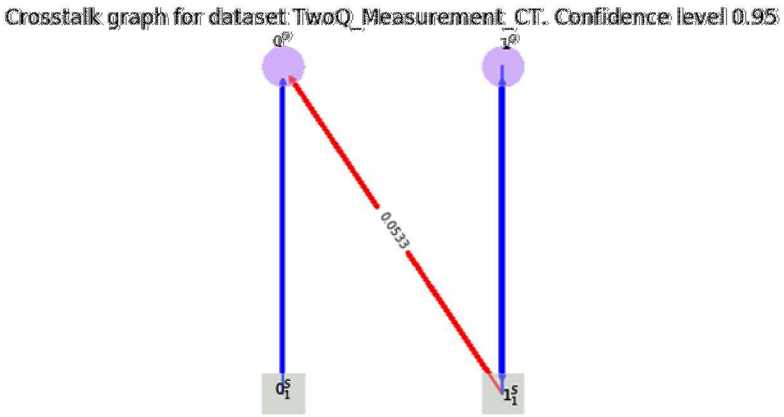
"Quantum" crosstalk



"Classical" crosstalk

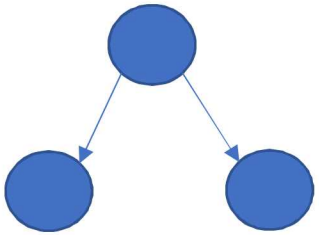


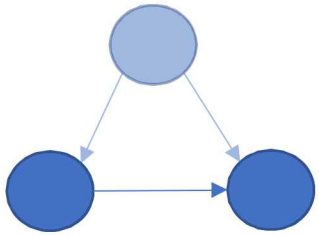
"SPAM" crosstalk



Summary and issues

- Statistically motivated, black-box method to detect and quantify crosstalk. Can state results with degree of confidence and error bars.
- Pro and con: the method captures many (all?) kinds of ”crosstalk”, but as a consequence doesn’t distinguish between them.
- **Key issue:** crosstalk detection is confounded by drift. Must perform drift analysis on the same data and/or design experiment carefully to minimize drift confounding.





Unobserved common cause looks like a direct association

Thanks!

Kenneth Rudinger
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Robin Blume-Kohout
Erik Nielsen

IARPA