

Title: Rob Spekkens ISSYP Keynote - Can Quantum Correlations be Explained Causally

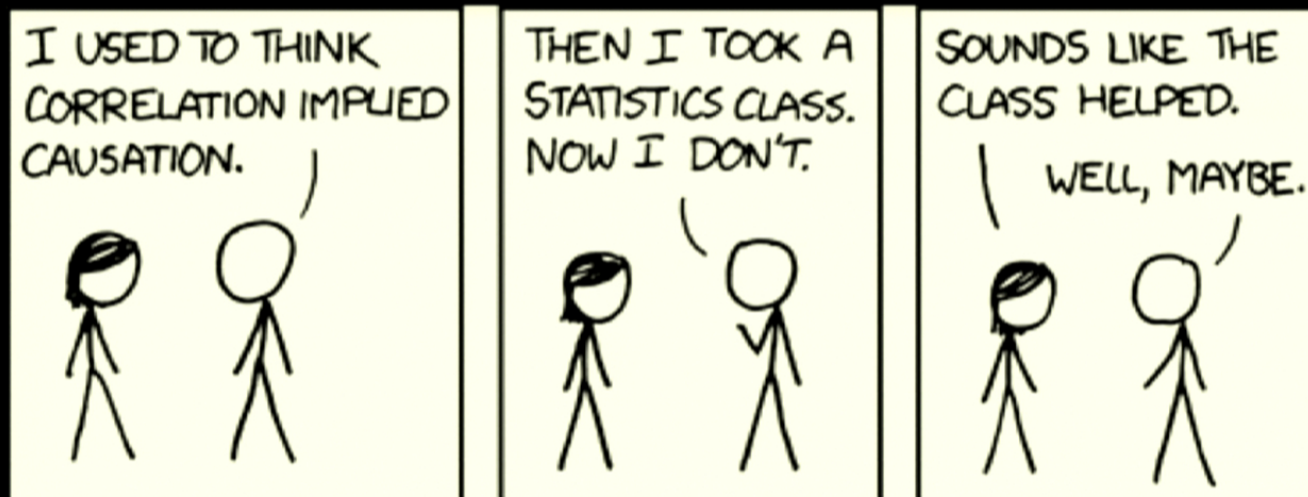
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URL: <http://pirsa.org/16070066>

Abstract:

Can Quantum Correlations Be Explained Causally?

Rob Spekkens
Perimeter Institute



From XKCD comics

ISSYP 2016



Simpson's Paradox

$$P(\text{recovery} \mid \text{drug}) > P(\text{recovery} \mid \text{no drug})$$

Simpson's Paradox

$$P(\text{recovery} \mid \text{drug}) > P(\text{recovery} \mid \text{no drug})$$

$$P(\text{recovery} \mid \text{drug, male}) < P(\text{recovery} \mid \text{no drug, male})$$

Simpson's Paradox

$$P(\text{recovery} \mid \text{drug}) > P(\text{recovery} \mid \text{no drug})$$

$$P(\text{recovery} \mid \text{drug, male}) < P(\text{recovery} \mid \text{no drug, male})$$

$$P(\text{recovery} \mid \text{drug, female}) < P(\text{recovery} \mid \text{no drug, female})$$

Recovery probability

	drug	no drug
male	180/300 = 60%	70/100 = 70%
female	20/100 = 20%	90/300 = 30%
combined	200/400 = 50%	160/400 = 40%

Simpson's Paradox

recovery



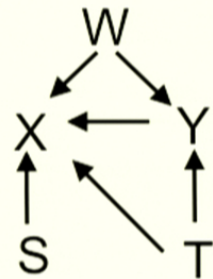
treatment



gender

Causal Model

Causal
Structure



Causal-Statistical
Parameters

$$P(W)$$

$$P(S)$$

$$P(T)$$

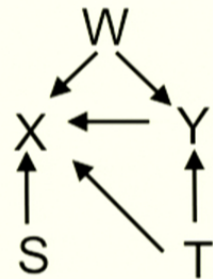
$$P(X|S, T, W, Y)$$

$$P(Y|T, W)$$

$$P(X, Y, W, S, T) = P(X|S, T, W, Y)P(Y|T, W)P(W)P(S)P(T)$$

Causal Model

Causal
Structure



Causal-Statistical
Parameters

$$P(W)$$

$$P(S)$$

$$P(T)$$

$$P(X|S, T, W, Y)$$

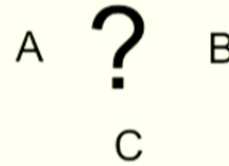
$$P(Y|T, W)$$

$$P(X, Y, W, S, T) = P(X|S, T, W, Y)P(Y|T, W)P(W)P(S)P(T)$$

$$P(A, B, C)$$

A is independent of B

$$P(A, B) = P(A)P(B)$$



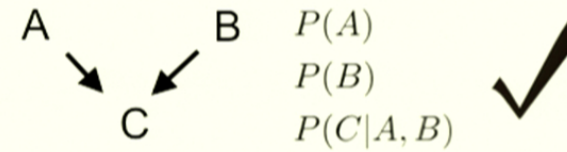
no other
independence
relations

$$P(A, B, C)$$

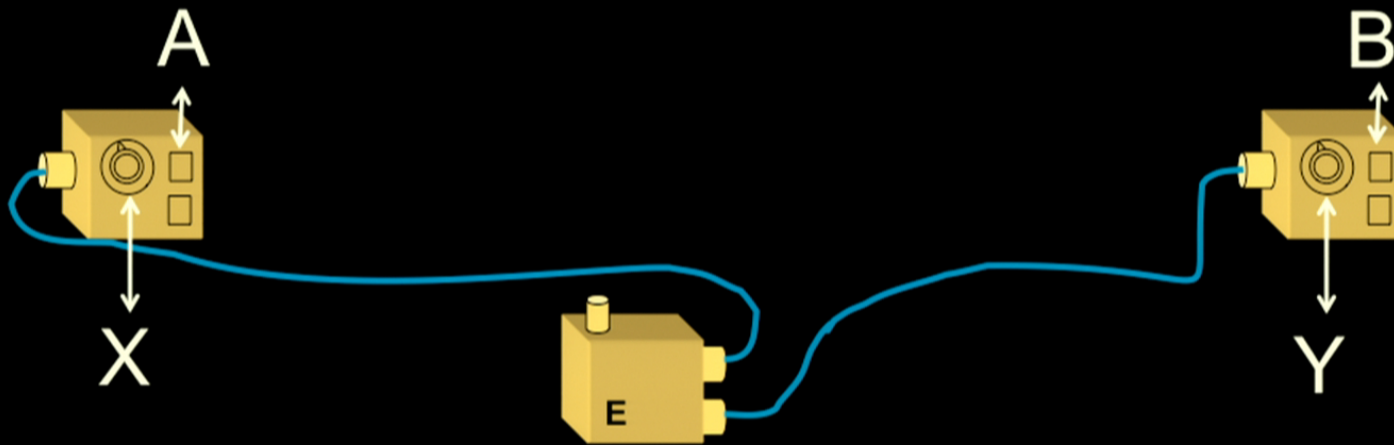
A is independent of B

$$P(A, B) = P(A)P(B)$$

no other
independence
relations



$$P(A, B, C) = P(C|A, B)P(A)P(B)$$

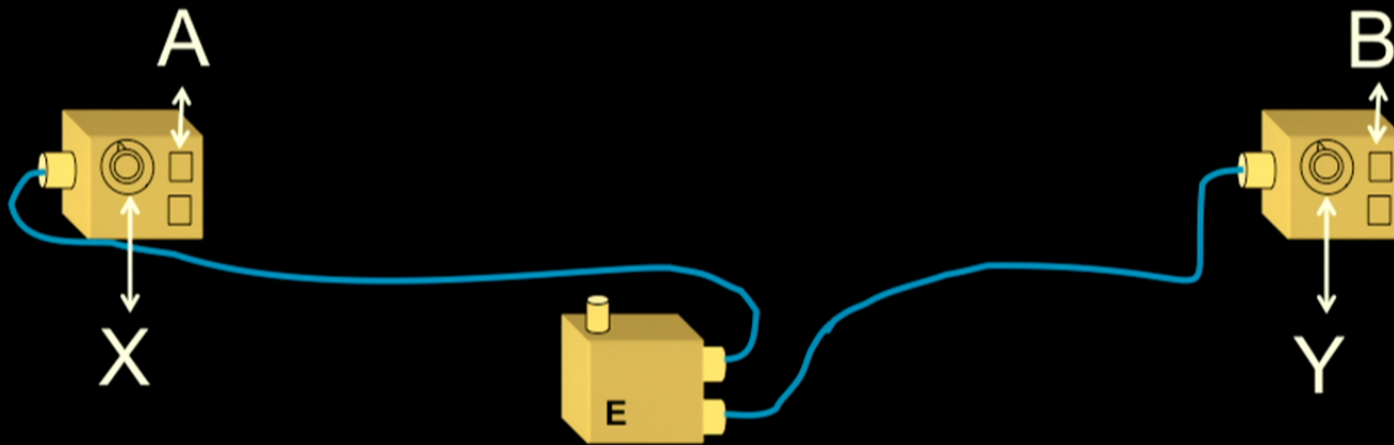


$P(A,B|X,Y)$

	A=0, B=0	A=0, B=1	A=1, B=0	A=1, B=1
X=0, Y=0	0.427	0.073	0.073	0.427
X=0, Y=1	0.427	0.073	0.073	0.427
X=1, Y=0	0.427	0.073	0.073	0.427
X=1, Y=1	0.073	0.427	0.427	0.073



A B
 ?
 X Y



$P(A,B|X,Y)$

	A=0, B=0	A=0, B=1	A=1, B=0	A=1, B=1
X=0, Y=0	0.427	0.073	0.073	0.427
X=0, Y=1	0.427	0.073	0.073	0.427
X=1, Y=0	0.427	0.073	0.073	0.427
X=1, Y=1	0.073	0.427	0.427	0.073

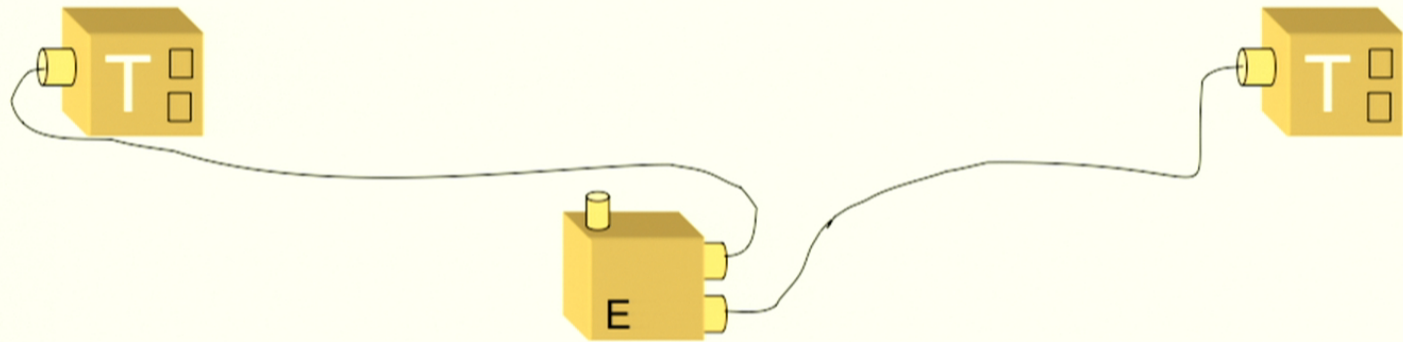


A B
 ?
 X Y

Bell's theorem



John S. Bell
(1928-1990)



There are two possible measurements, H and T,
with two outcomes each: green or red

Suppose which of H or T occurs at each wing is chosen at random

Scenario 1

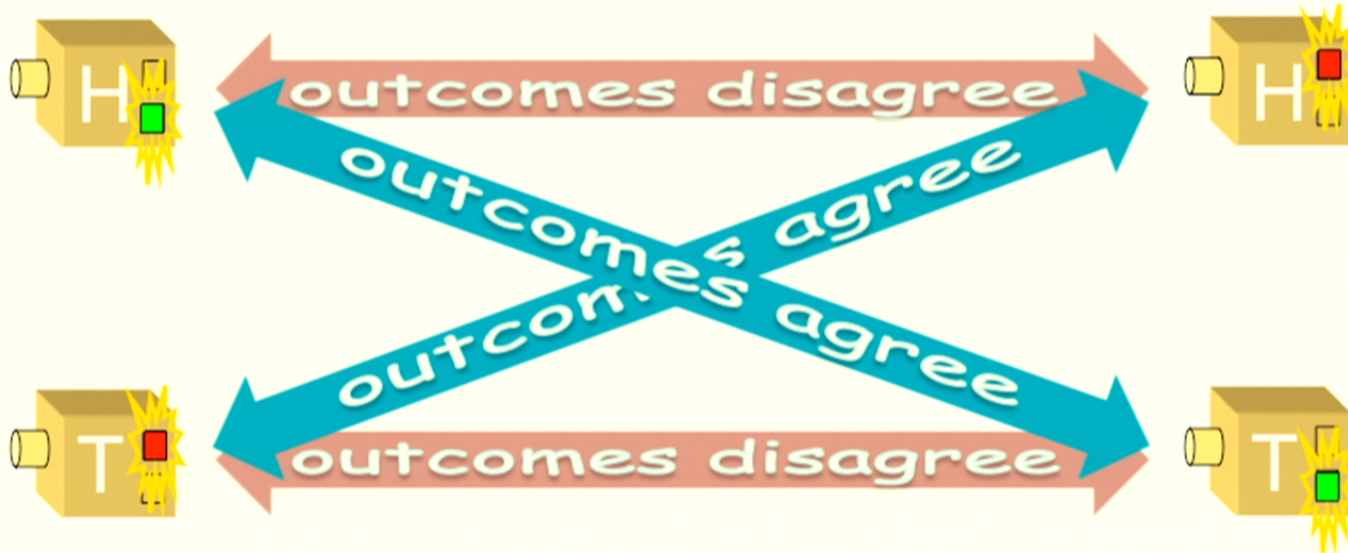
1. Whenever the **same** measurement is made on A and B, the outcomes always **agree**
H and H
or
T and T
2. Whenever **different** measurements are made on A and B, the outcomes always **disagree**
H and T
or
T and H

There are two possible measurements, H and T,
with two outcomes each: green or red

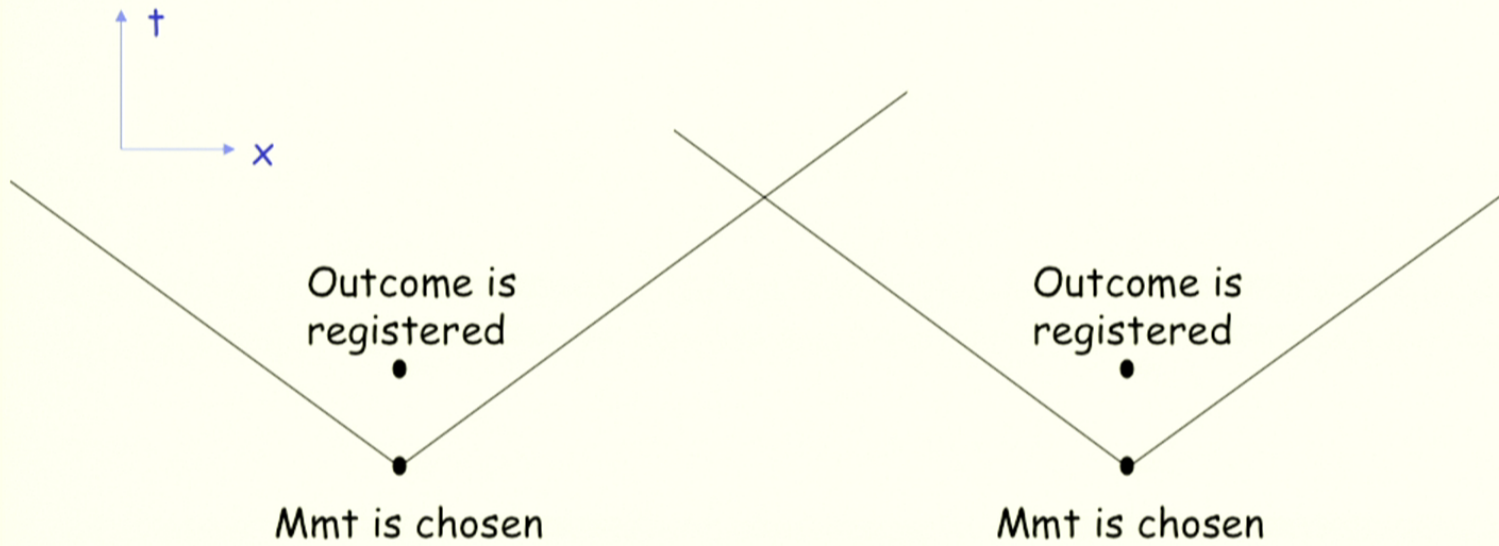
Suppose which of H or T occurs at each wing is chosen at random

Scenario 2

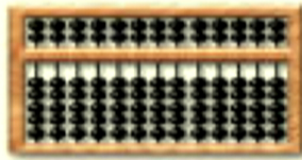
1. Whenever the **same** measurement is made on A and B, the outcomes always **disagree**
H and H
or
T and T
2. Whenever **different** measurements are made on A and B, the outcomes always **agree**
H and T
or
T and H



Tension with the theory of relativity



Information theory

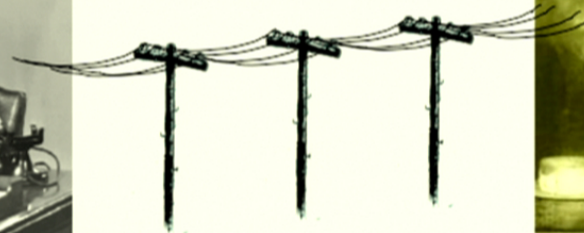


Computation

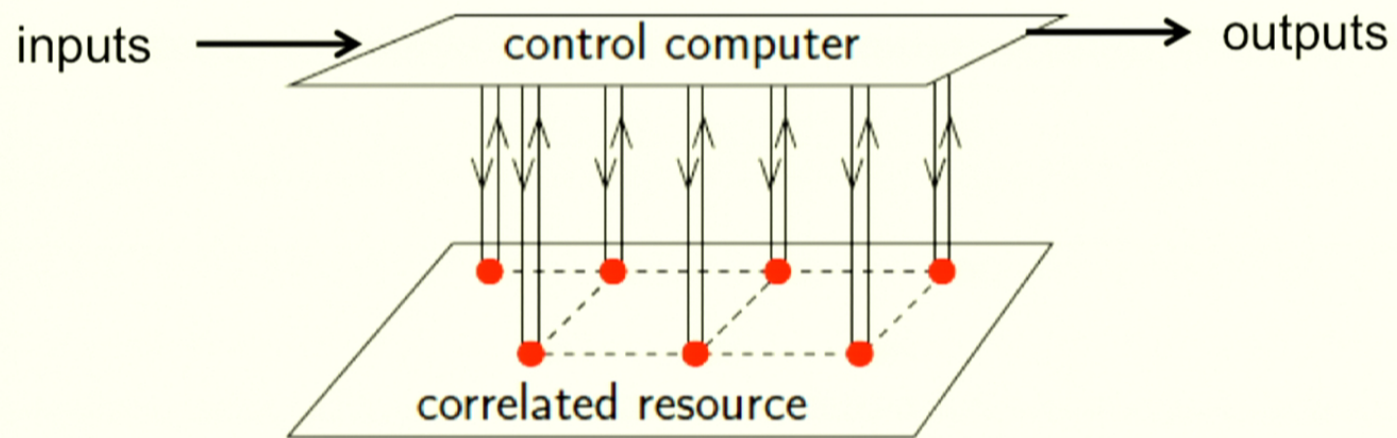
- factoring
- Searching a database

Communication

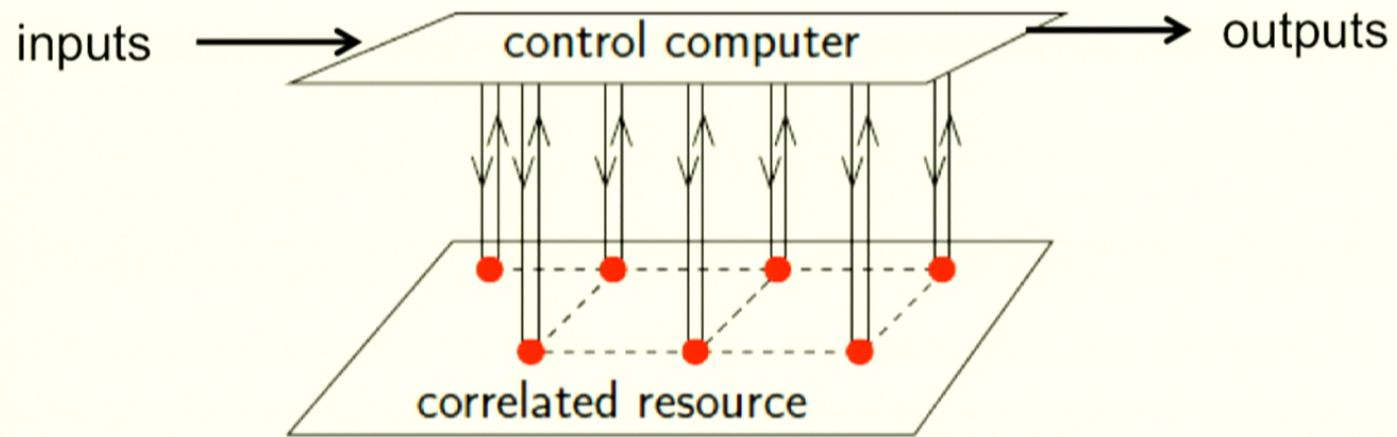
- data compression
- overcoming noise



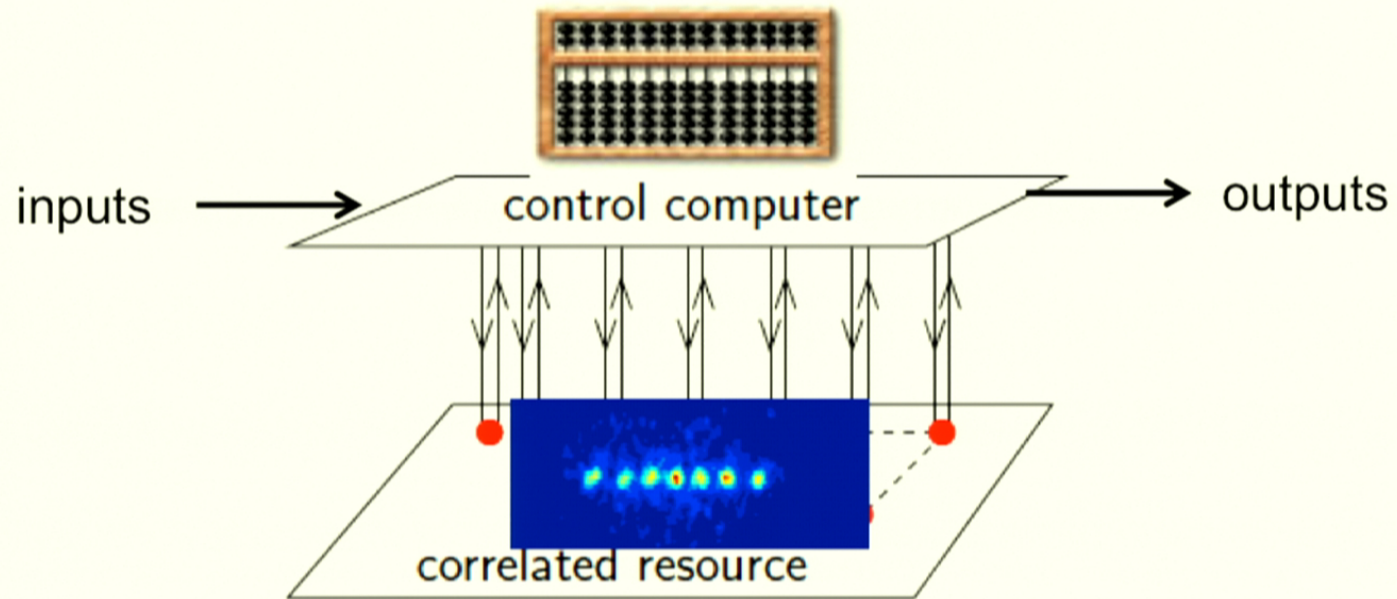
Quantum advantages for computation

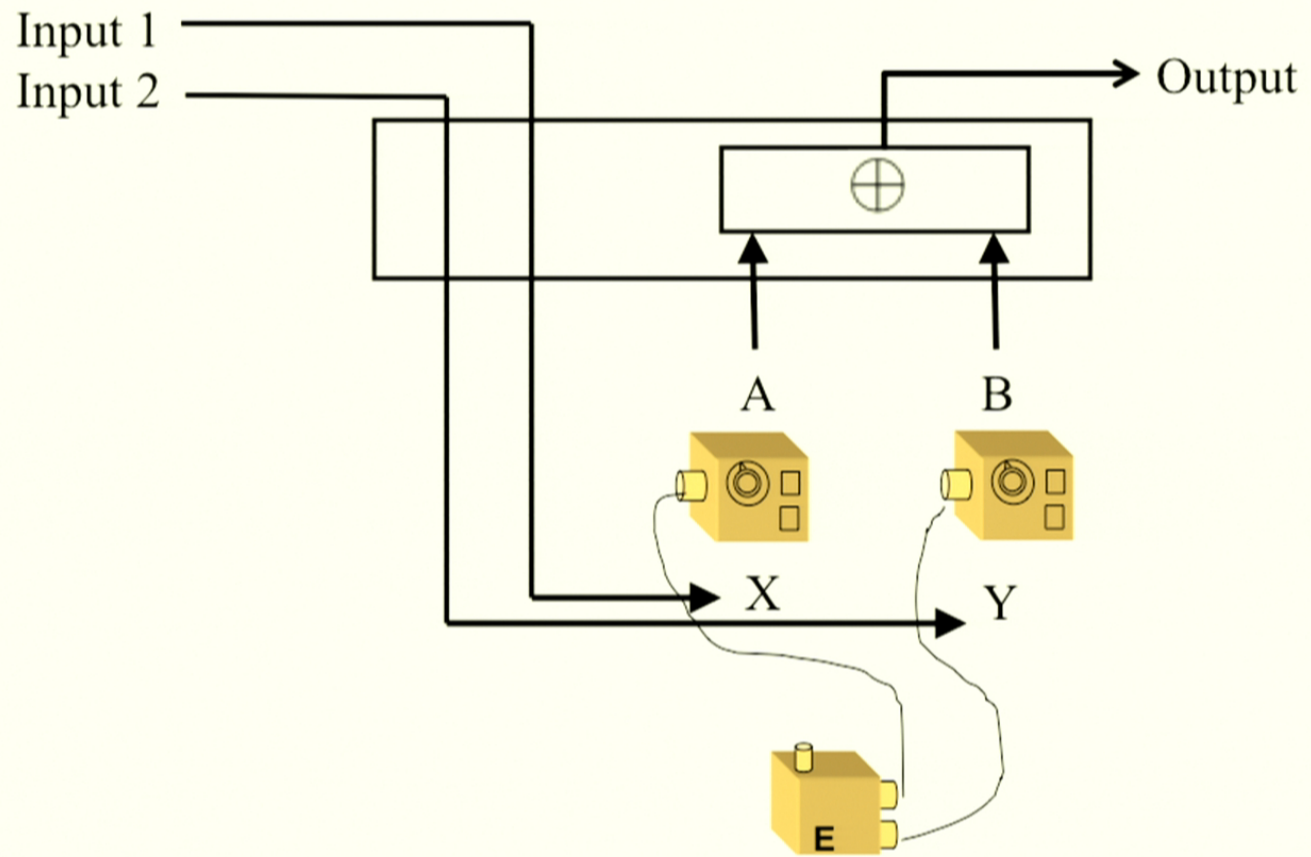


Quantum advantages for computation



Quantum advantages for computation





Input 1
Input 2

Output

$P(A, B|X, Y)$

	A=0, B=0	A=0, B=1	A=1, B=0	A=1, B=1
X=0, Y=0	1/2	0	0	1/2
X=0, Y=1	1/2	0	0	1/2
X=1, Y=0	1/2	0	0	1/2
X=1, Y=1	0	1/2	1/2	0

$$A \oplus B = XY$$

