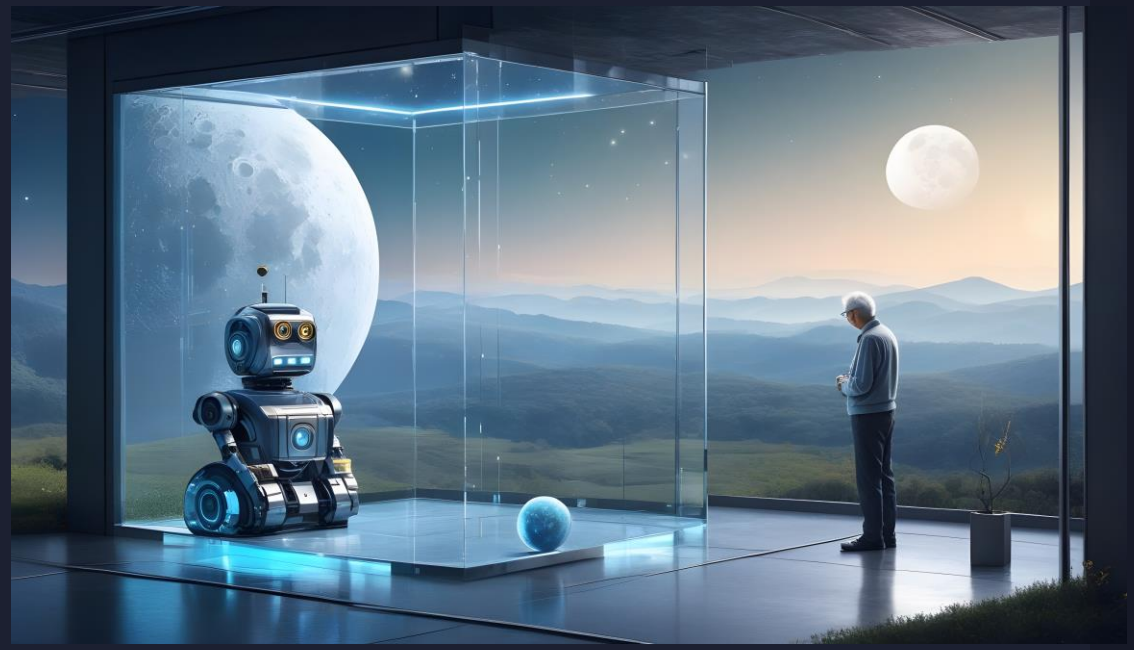
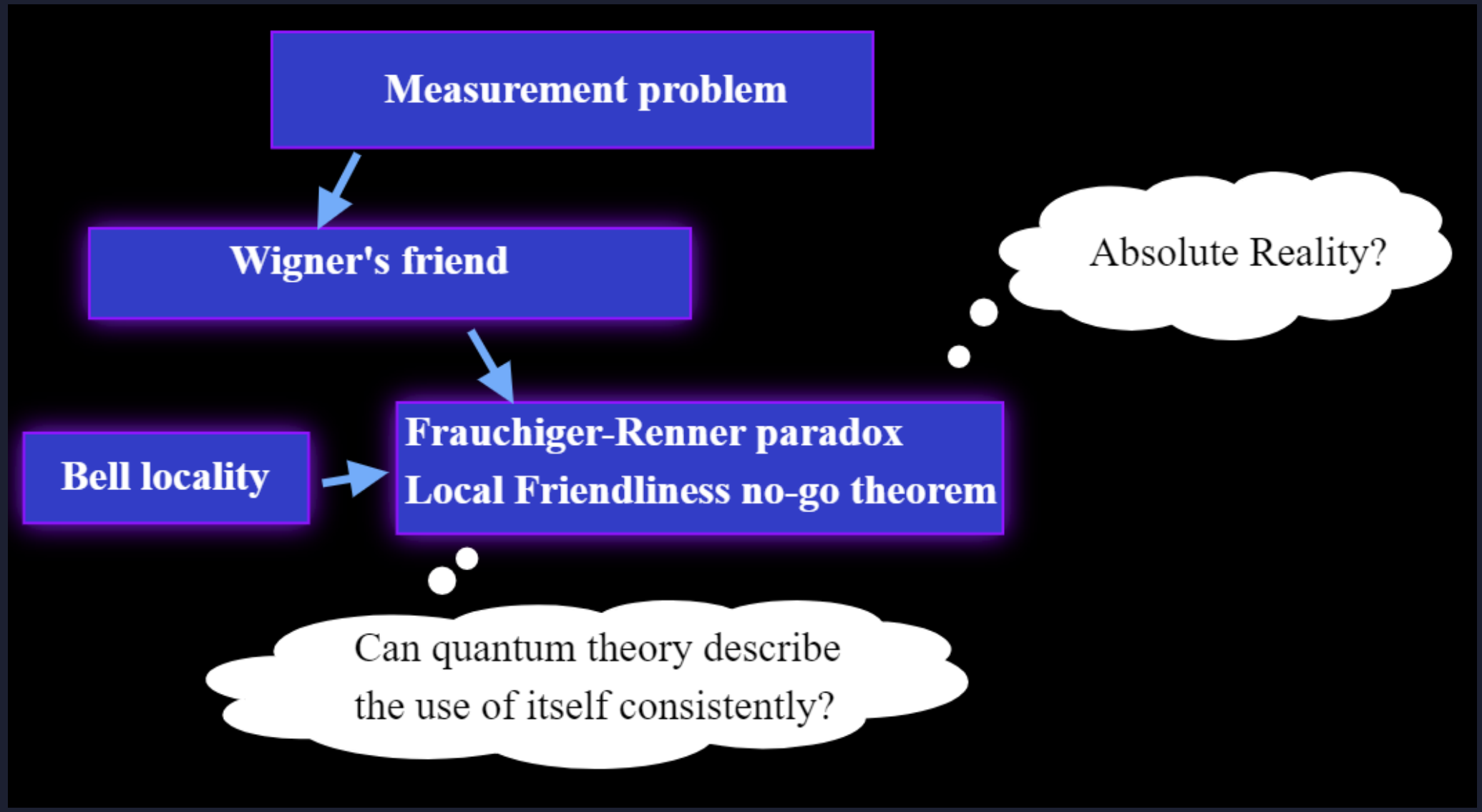
LOCAL FRIENDLINESS, CONTEXTUALITY AND WIGNER'S FRIENDS

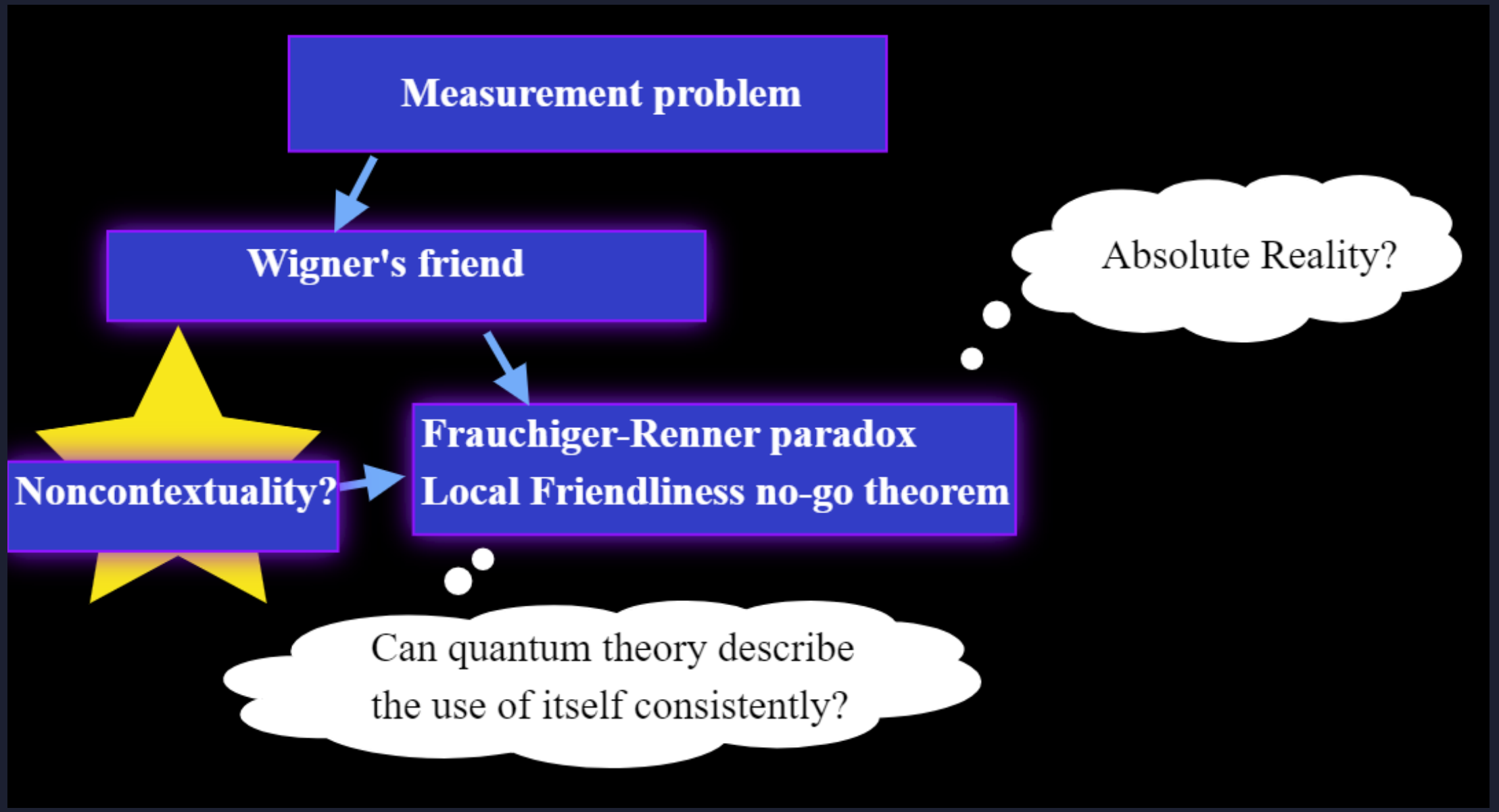


Laurens Walleghem,
Joint work with: Rui Soares Barbosa, Rafael Wagner, David Schmid, Yìlè Ying, Stefan Weigert, Matthew Pusey

TOPIC


Measurement problem
Wigner's friend
Bell locality
Frauchiger-Renner paradox
Local Friendliness no-go theorem
Absolute Reality?
Can quantum theory describe
the use of itself consistently?

TOPIC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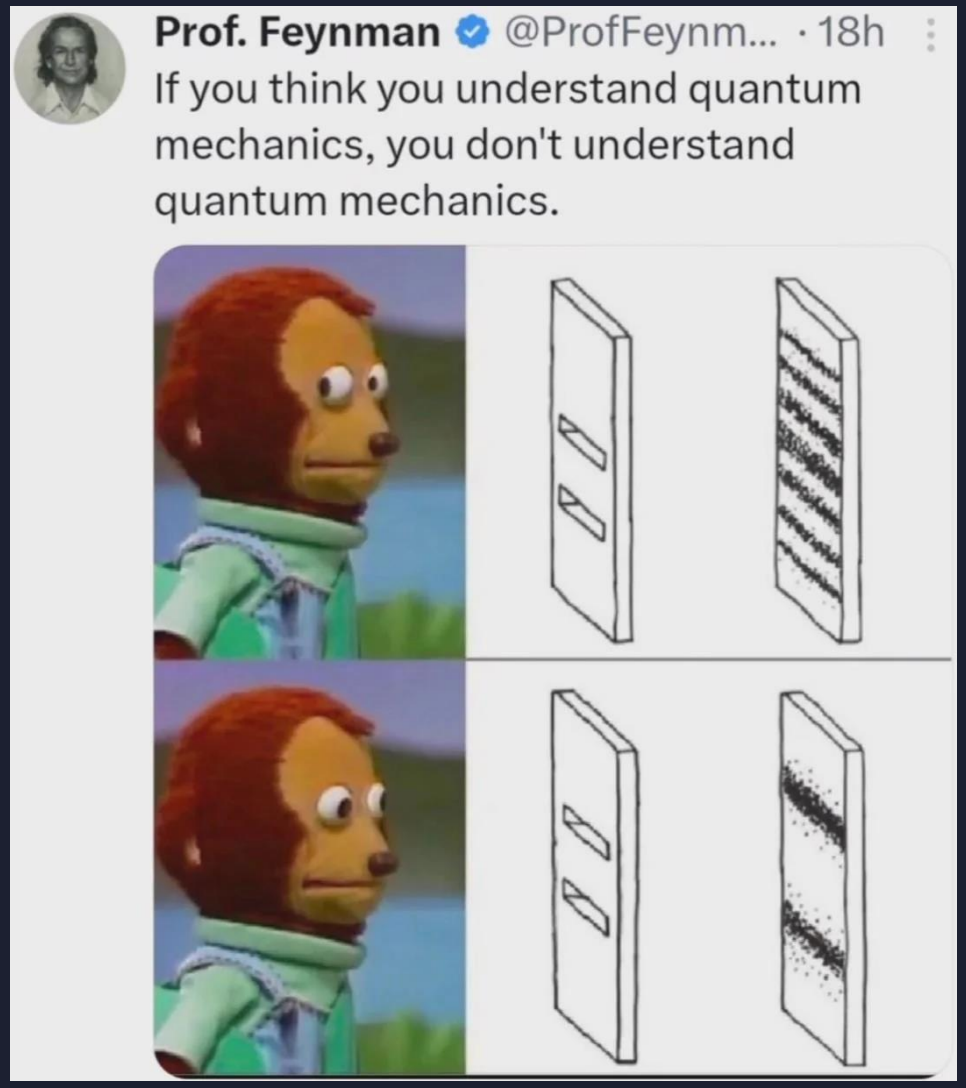
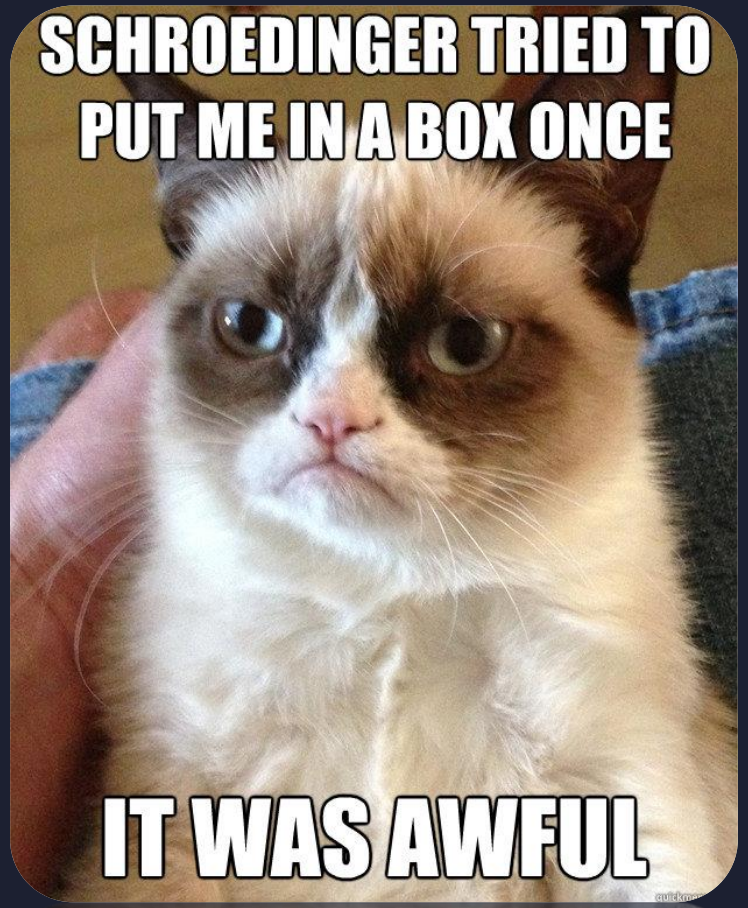

Prof. Feynman @ProfFeynm... · 18h
If you think you understand quantum mechanics, you don't understand quantum mechanics.

TOPIC

Measurement problem



What is the measurement problem?

- *A theory making predictions incompatible with measurement outcomes being absolute?* *(Vilasini, Ormrod, Barrett, 2023)*
- *…how, or whether, wavefunction collapse occurs* *(wikipedia)*
- *…collapse and unitary evolution cannot be reconciled. This is the core of the "big" measurement problem* *(Baumann et al 2016, Bong et al 2020)*
- *How to reconcile the vastness of the Hilbert space of possible states with the observation of a comparatively few "classical" macrosopic states, defined by having a small number of determinate and robust properties such as position and momentum?* *(Schlosshauser 2005)*

TOPIC

Measurement problem

Wigner's friend

TOPIC

Measurement problem

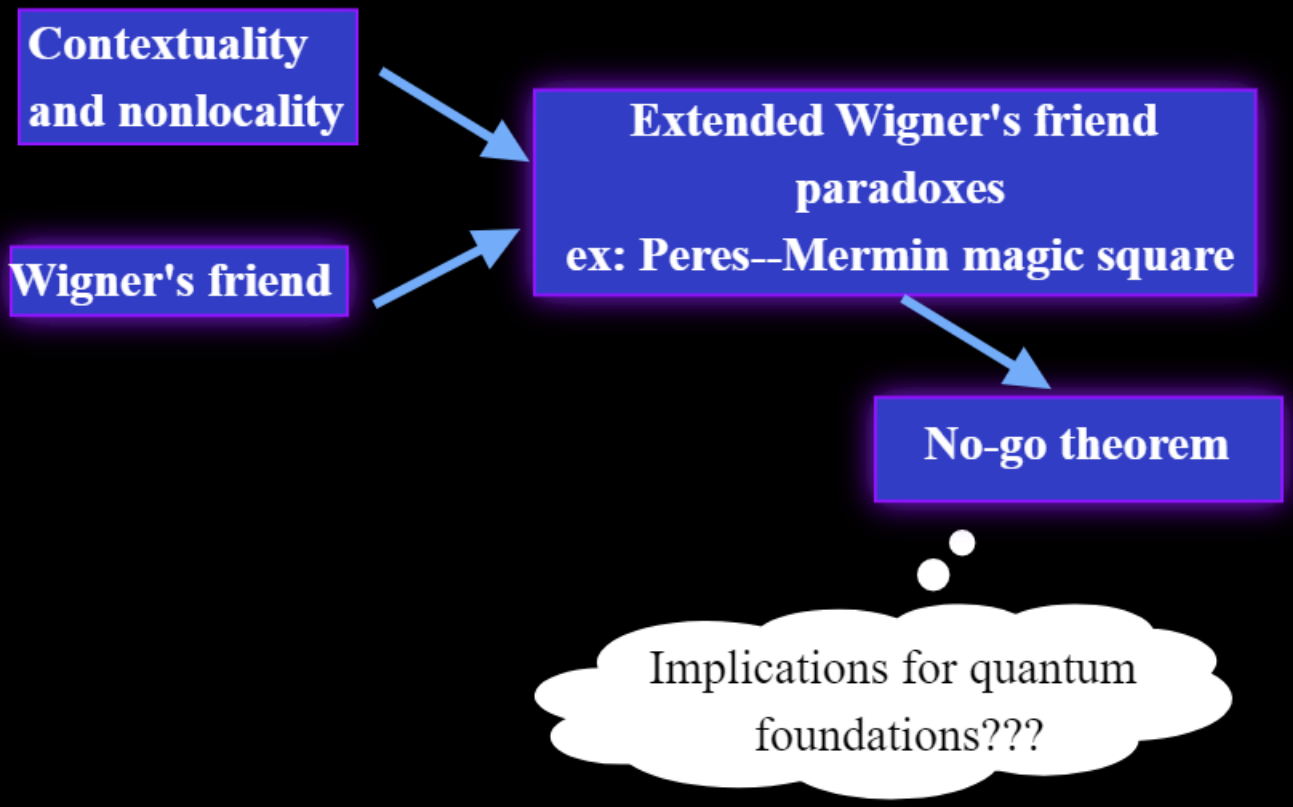
Wigner's friend

Can quantum theory describe the use of itself consistently?

Local friendliness & FR no-go theorems

Are events absolute?

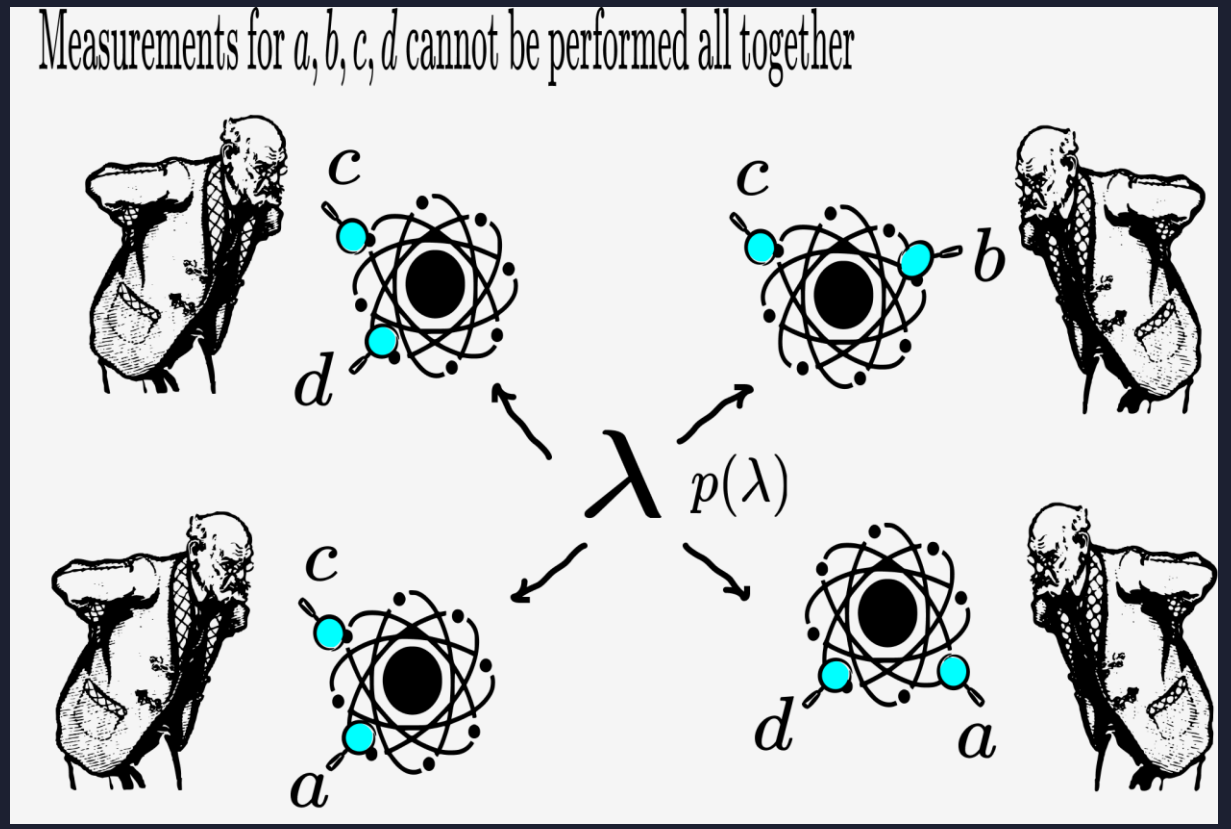
CONTENTS


Contextuality and nonlocality
Wigner's friend
Extended Wigner's friend paradoxes
ex: Peres--Mermin magic square
No-go theorem
Implications for quantum foundations???

CONTEXTUALITY AND NONLOCALITY

What is nonclassicality?

CONTEXTUALITY AND NONLOCALITY

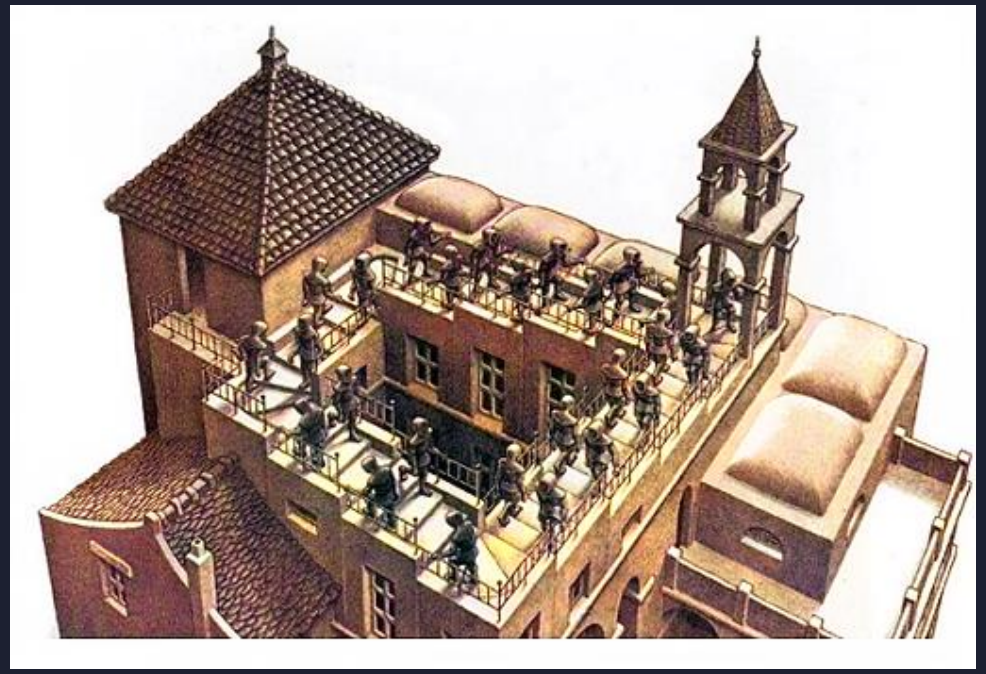


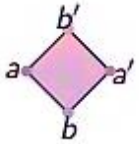
Assign values simultaneously (from underlying classical sampling hidden variable)

Locally consistent but globally inconsistent!

CONTEXTUALITY AND NONLOCALITY

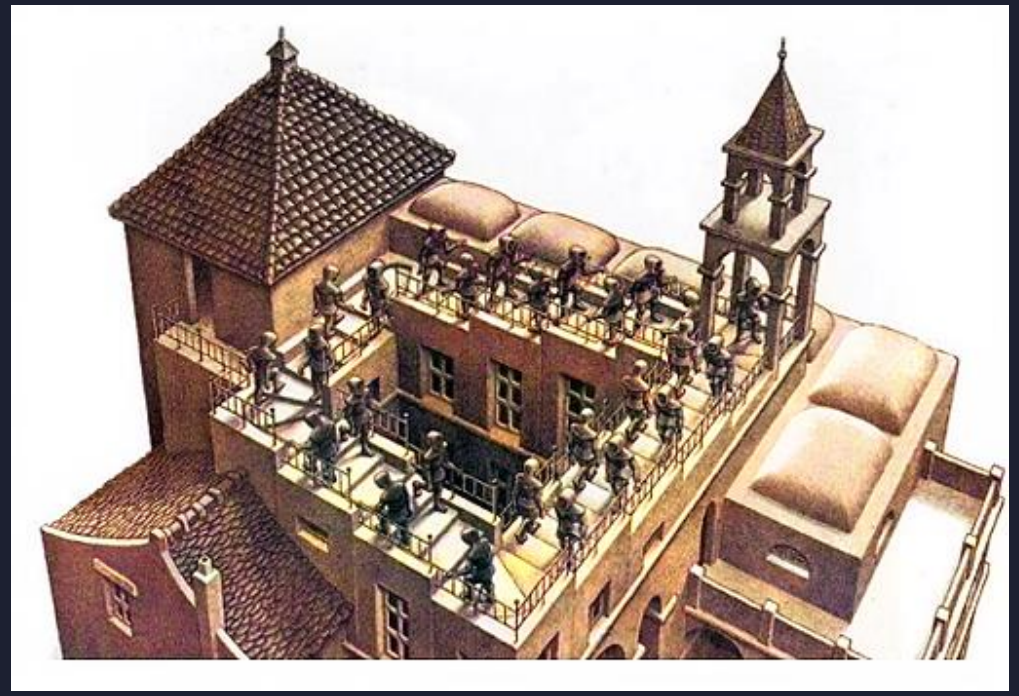
Locally consistent but globally inconsistent!



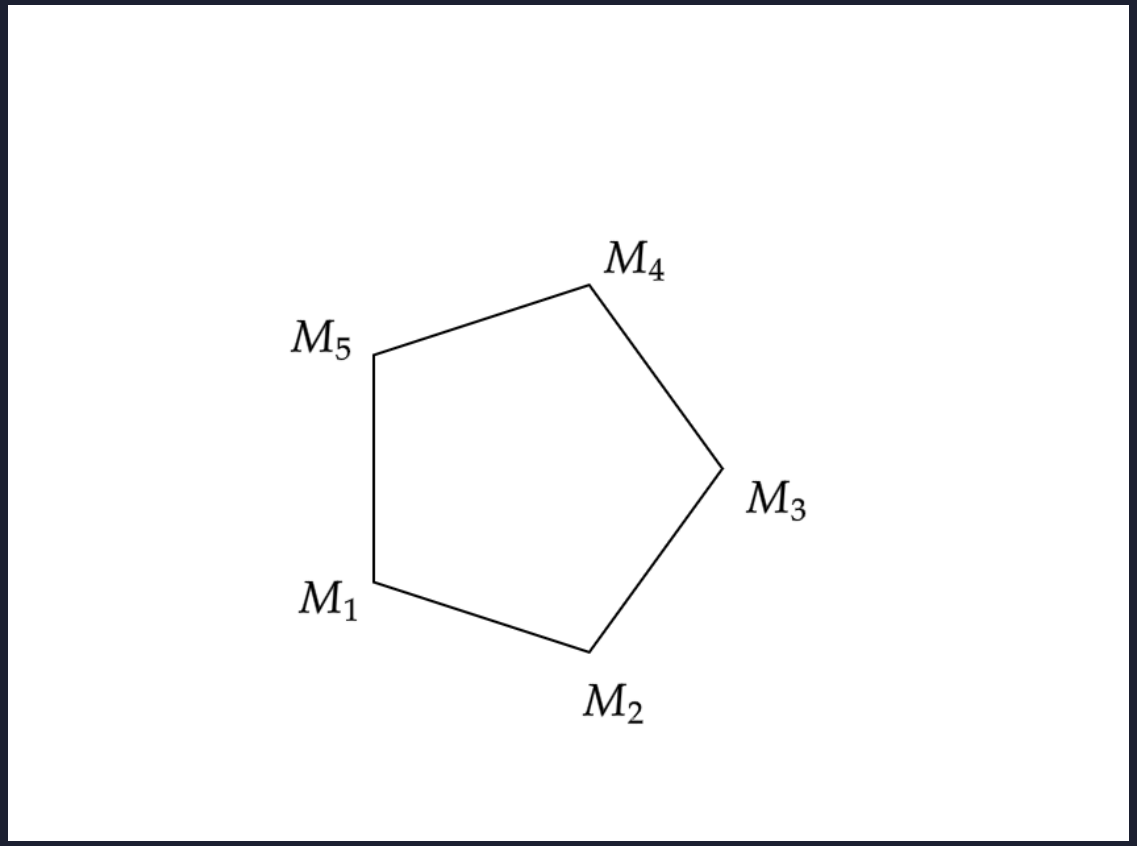

b′
a
a′
b

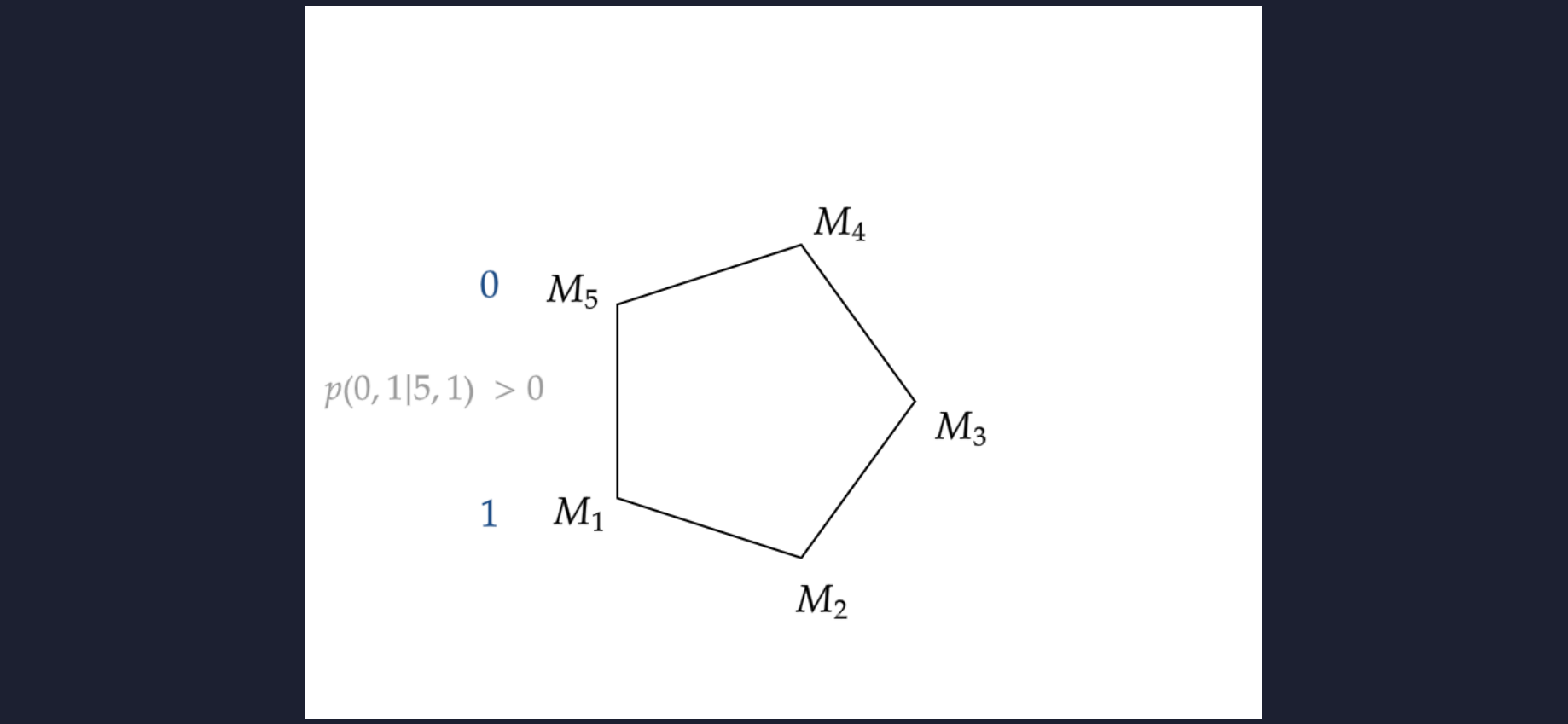
CONTEXTUALITY AND NONLOCALITY

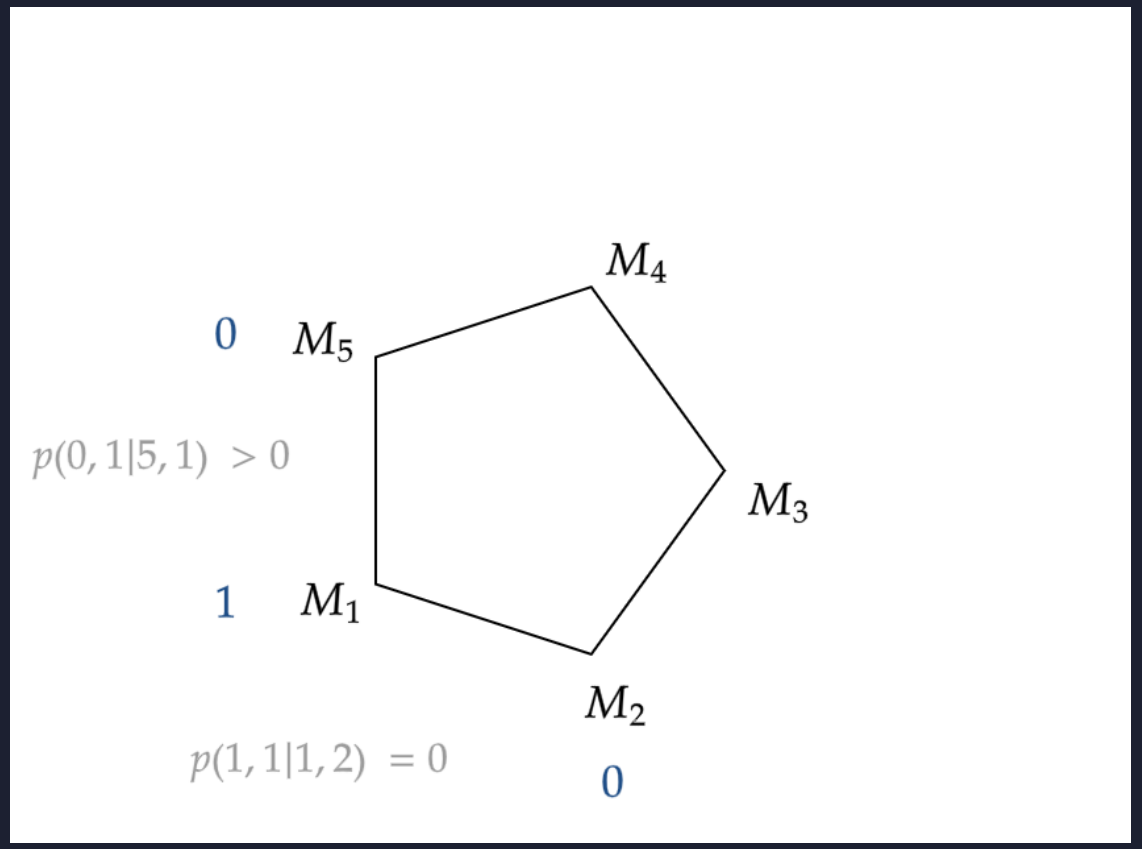
Locally consistent but globally inconsistent!

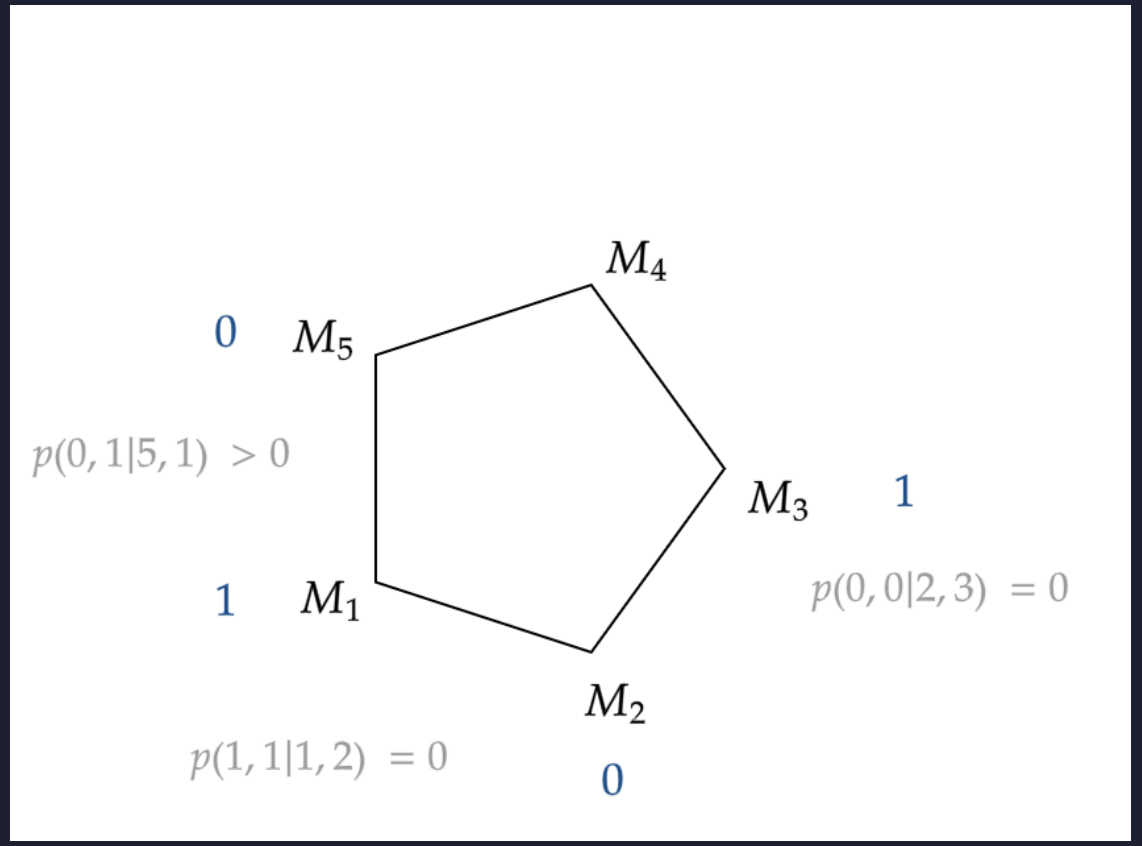


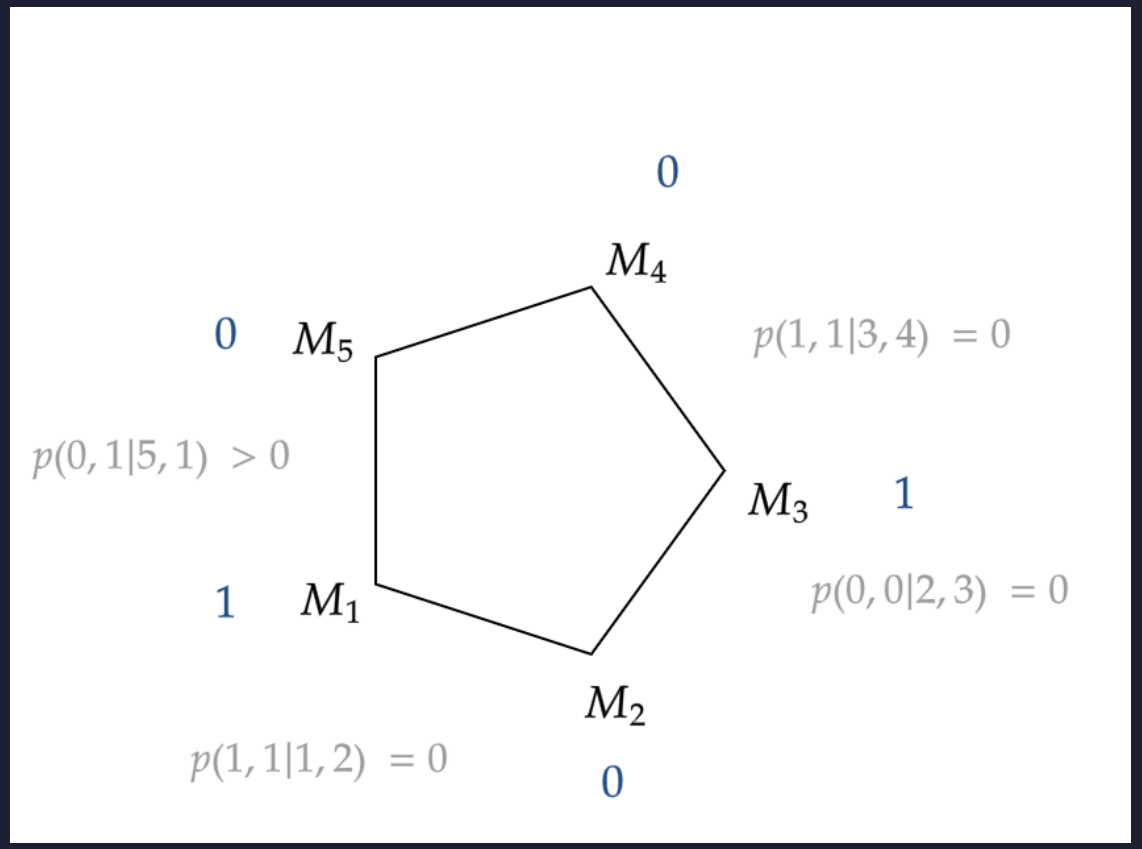
5-CYCLE CONTEXTUALITY

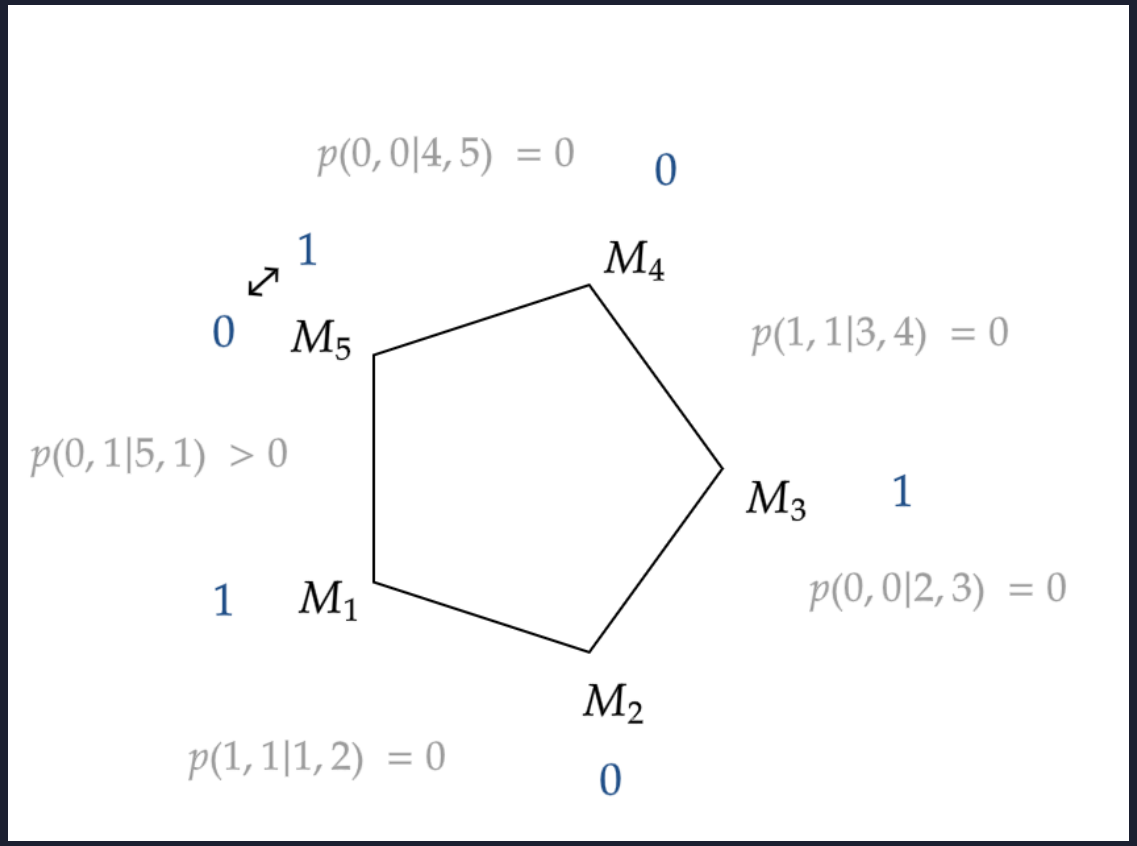



M_4
0
M_5
$p(0,1|5,1) > 0$
M_3
1
M_1
M_2


M_4
0
M_5
$p(0,1|5,1) > 0$
M_3
1
M_1
M_2
$p(1,1|1,2) = 0$
0


M_4
0
M_5
$p(0,1|5,1) > 0$
M_3
1
1
M_1
$p(0,0|2,3) = 0$
M_2
$p(1,1|1,2) = 0$
0


0
M_4
0
M_5
$p(1,1|3,4) = 0$
$p(0,1|5,1) > 0$
M_3
1
1
M_1
$p(0,0|2,3) = 0$
M_2
$p(1,1|1,2) = 0$
0


$p(0,0|4,5) = 0$
0
1
M_4
0
M_5
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$p(0,1|5,1) > 0$
M_3
1
1
M_1
$p(0,0|2,3) = 0$
M_2
$p(1,1|1,2) = 0$
0

CONTEXTUALITY AND NONLOCALITY: PERES-MERMIN MAGIC SUARE

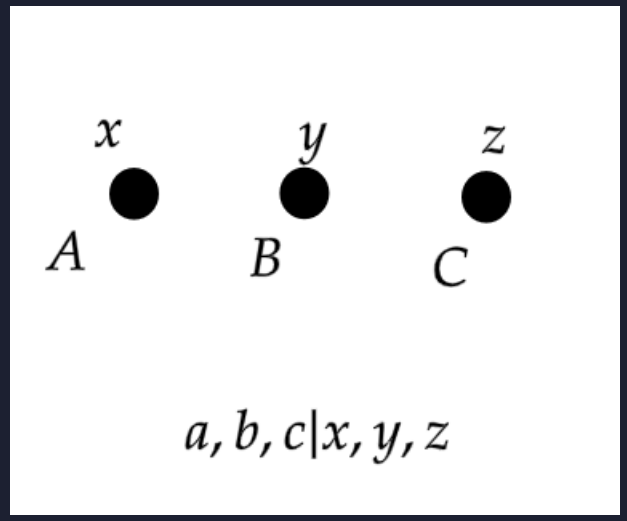
$$\begin{bmatrix} A & a & \alpha \\ B & b & \beta \\ C & c & \gamma \end{bmatrix}$$

Outcomes in {1,-1}

$$\langle Aa\alpha \rangle = 1, \quad \langle Bb\beta \rangle = 1, \quad \langle Cc\gamma \rangle = 1,$$
$$\langle ABC \rangle = -1, \quad \langle abc \rangle = -1, \quad \langle \alpha\beta\gamma \rangle = -1.$$

CONTEXTUALITY AND NONLOCALITY

- Nonlocality as a special instance of contextuality
- Measurements contexts arise from party-structure!



WIGNER'S FRIEND

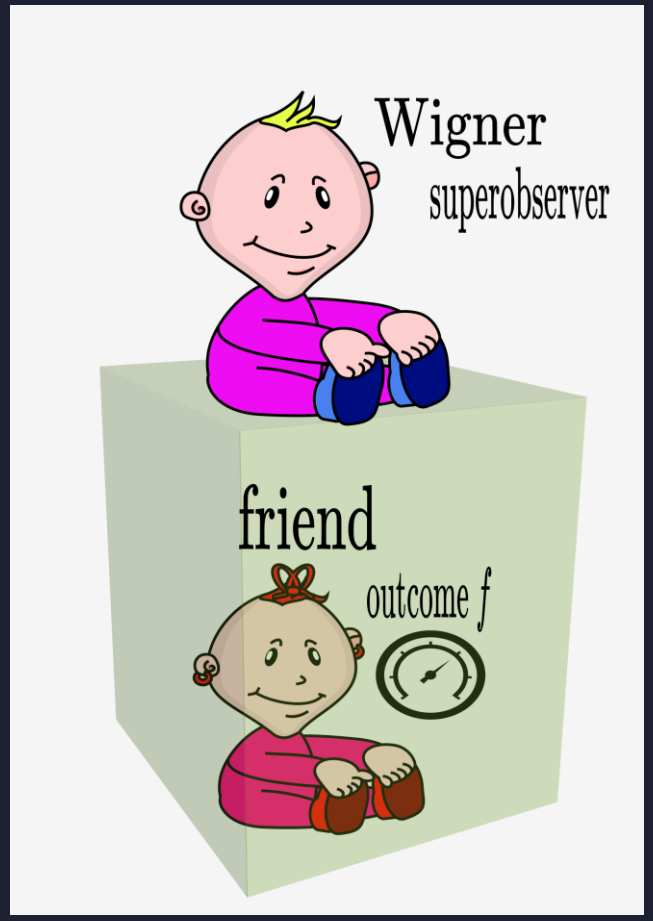
What if Quantum Theory is Universal?

WIGNER'S FRIEND

$$|0\rangle_F \otimes |0\rangle_S \rightarrow |0\rangle_F \otimes |0\rangle_S$$
$$|0\rangle_F \otimes |1\rangle_S \rightarrow |1\rangle_F \otimes |1\rangle_S$$

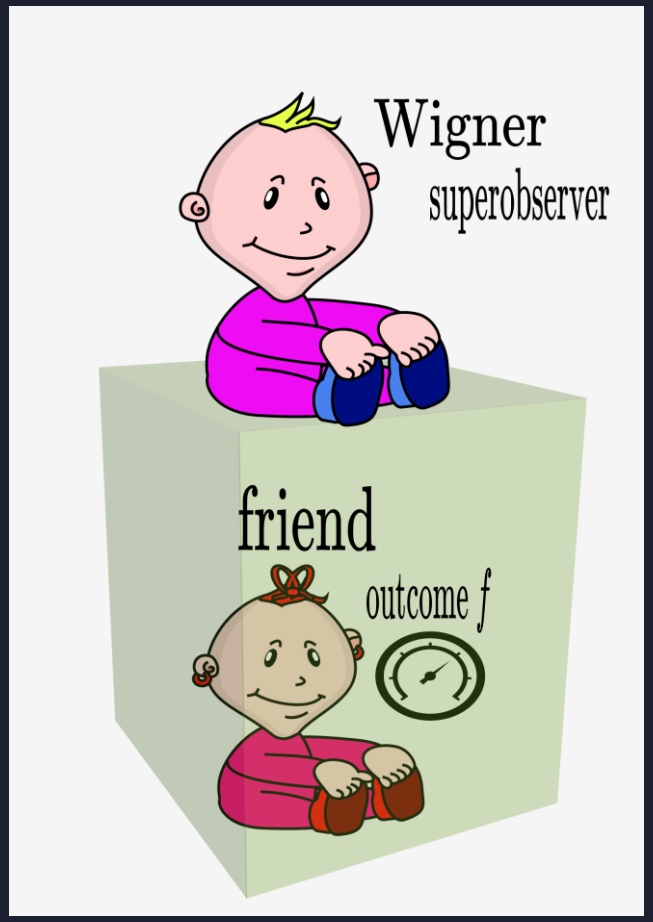
Using linearity of unitary map

$$|0\rangle_F \otimes |\psi\rangle_S = |0\rangle_F \otimes \sqrt{\frac{1}{2}}(|0\rangle + |1\rangle)_S \rightarrow \sqrt{\frac{1}{2}}(|00\rangle + |11\rangle)_S$$



Incompatibility of absolute collapse and universality of quantum theory

WIGNER'S FRIEND



Incompatibility of absolute collapse and universality of quantum theory

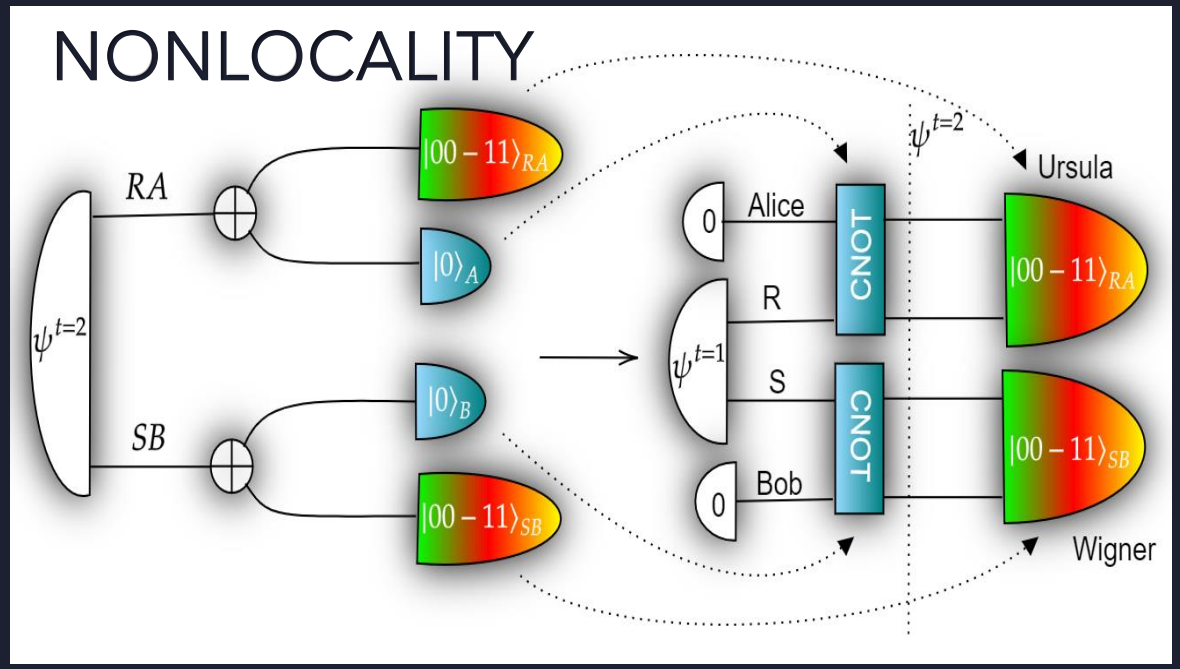
Friend: Quantum AI?

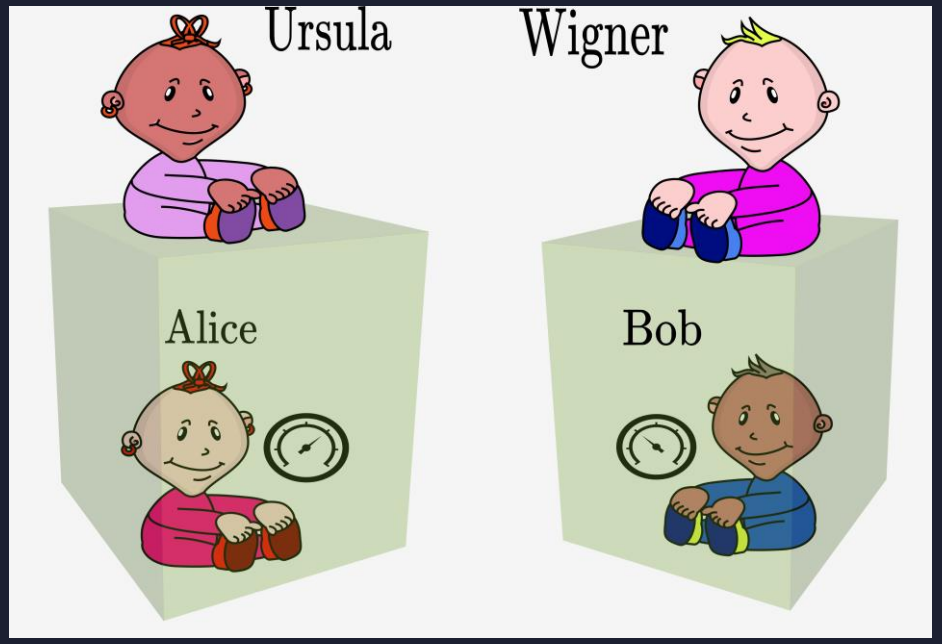
LOCAL FRIENDLINESS NO-GO THEOREM

= Nonlocality (Hardy) + Wigner's friends

LOCAL FRIENDLINESS ORIGINAL SCENARIO

$$p_{emp}(ab|xy)$$





LOCAL FRIENDLINESS ASSUMPTIONS

Assumption A1 (Absoluteness of Observed Events (AOE)). *An observed event is an absolute single event, not relative to anything or anyone.*

Assumption A2 (No-Superdeterminism). *Any set of events on a spacelike hypersurface is uncorrelated with any set of subsequent freely chosen actions.*

Assumption A3 (LF-Locality). *The probability of an event does not change when conditioning on a spacelike-separated free choice z, even if it is already conditioned on other events outside the future lightcone of z.*

LOCAL FRIENDLINESS ASSUMPTIONS

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$$p_{emp}(ab|xy) = \sum_{c,d} p(abcd|xy), \forall a, b, x, y$$

$$p(a|cd, x = 1, y) = \delta_{a,c}, \forall a, c, d, y$$

$$p(b|cd, x, y = 1) = \delta_{b,d}, \forall b, c, d, x$$

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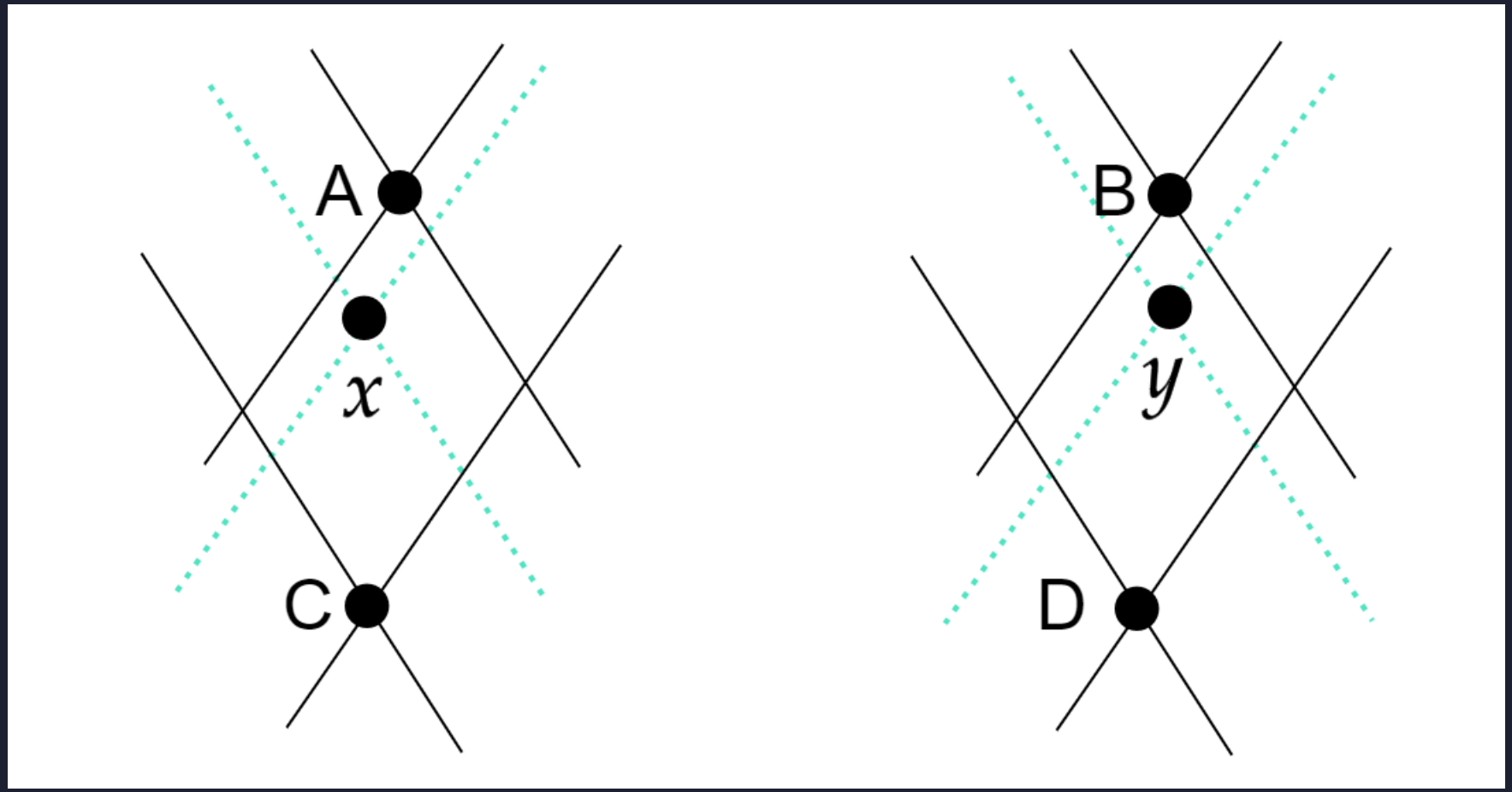
A
x
C
B
y
D

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$$p(cd|xy) = p(cd)$$

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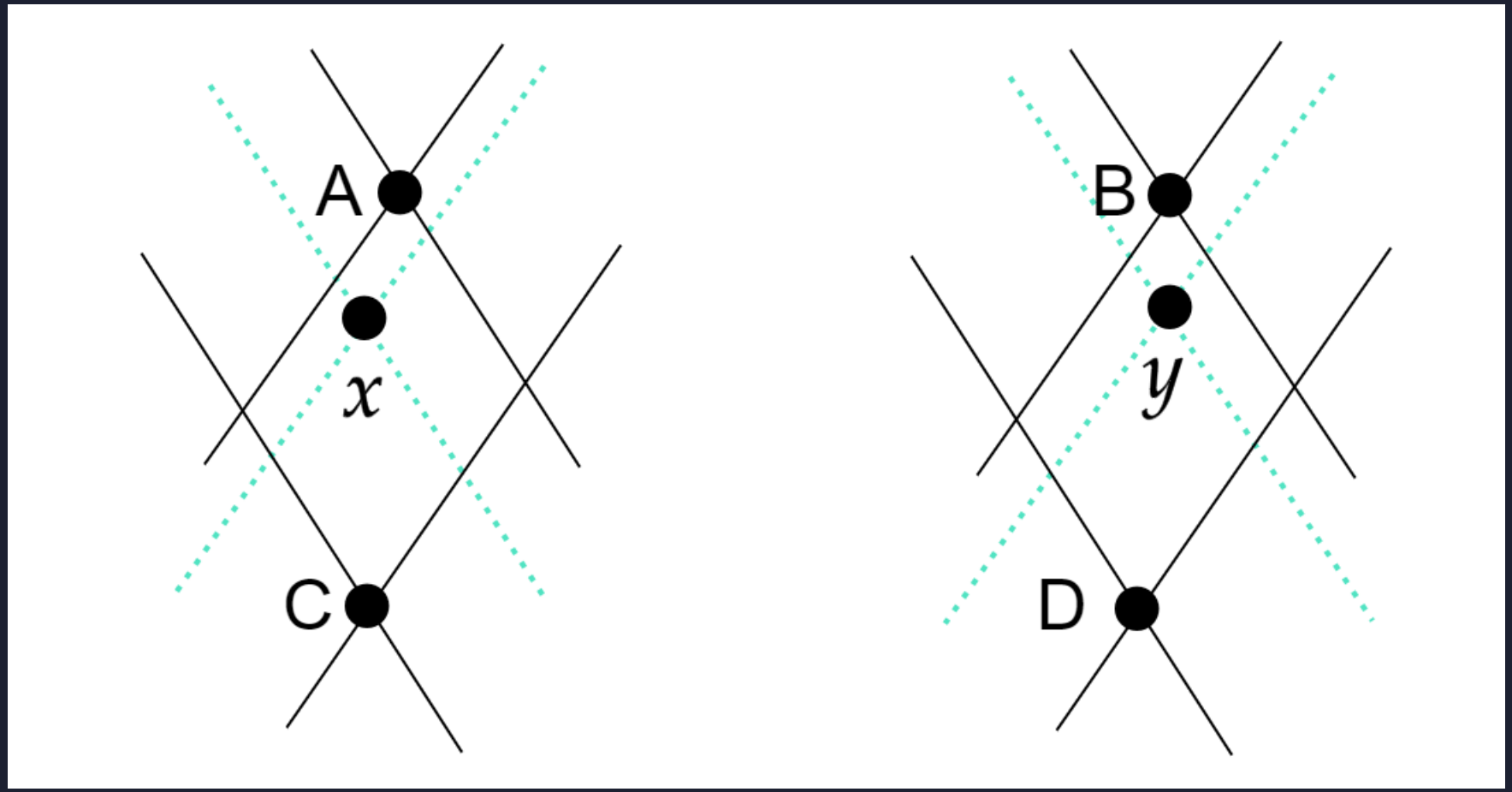
A
x
C
B
y
D

LOCAL FRIENDLINESS ASSUMPTIONS

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$$p(cd|xy) = p(cd)$$

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$$p(a|cdxy) = p(a|cdx)$$

$$p(b|cdxy) = p(b|cdy)$$

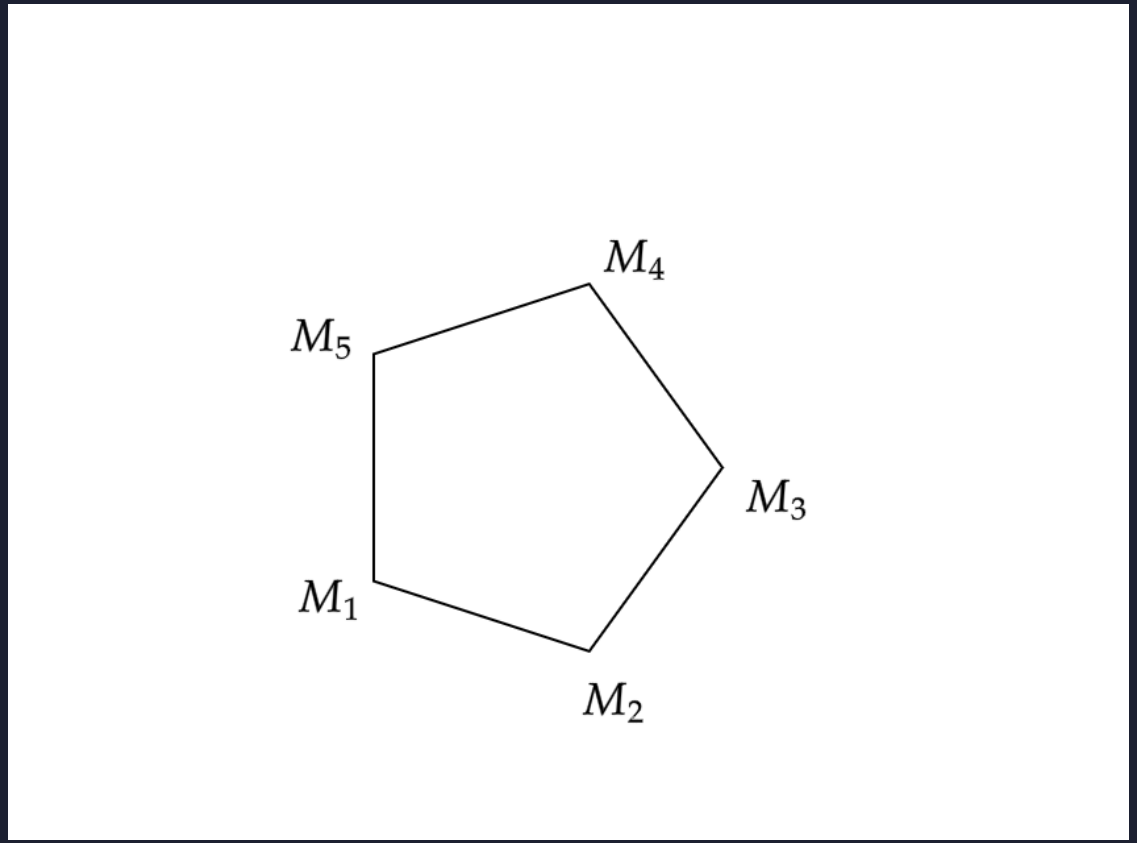
Theorem 3 (LF no-go theorem)**.** *If a superobserver can perform any quantum operation on an observer and its environment, then all three LF assumptions together, namely AOE, No-Superdeterminism and Locality, cannot hold in a physical theory.*

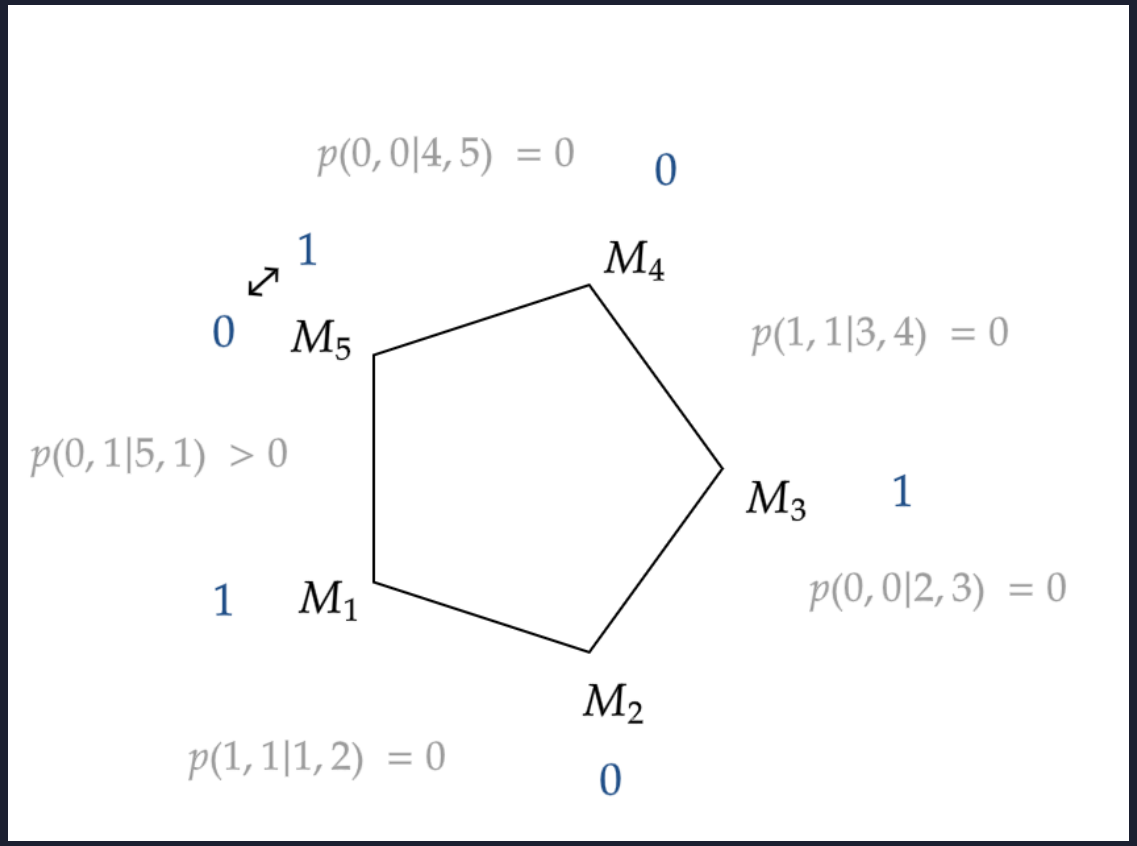
A LOCAL FRIENDLINESS PARADOX BASED ON THE 5-CYCLE

= 5-cycle (possibilistic) contextuality +

Wigner's friends

RECAP OF 5-CYCLE CONTEXTUALITY



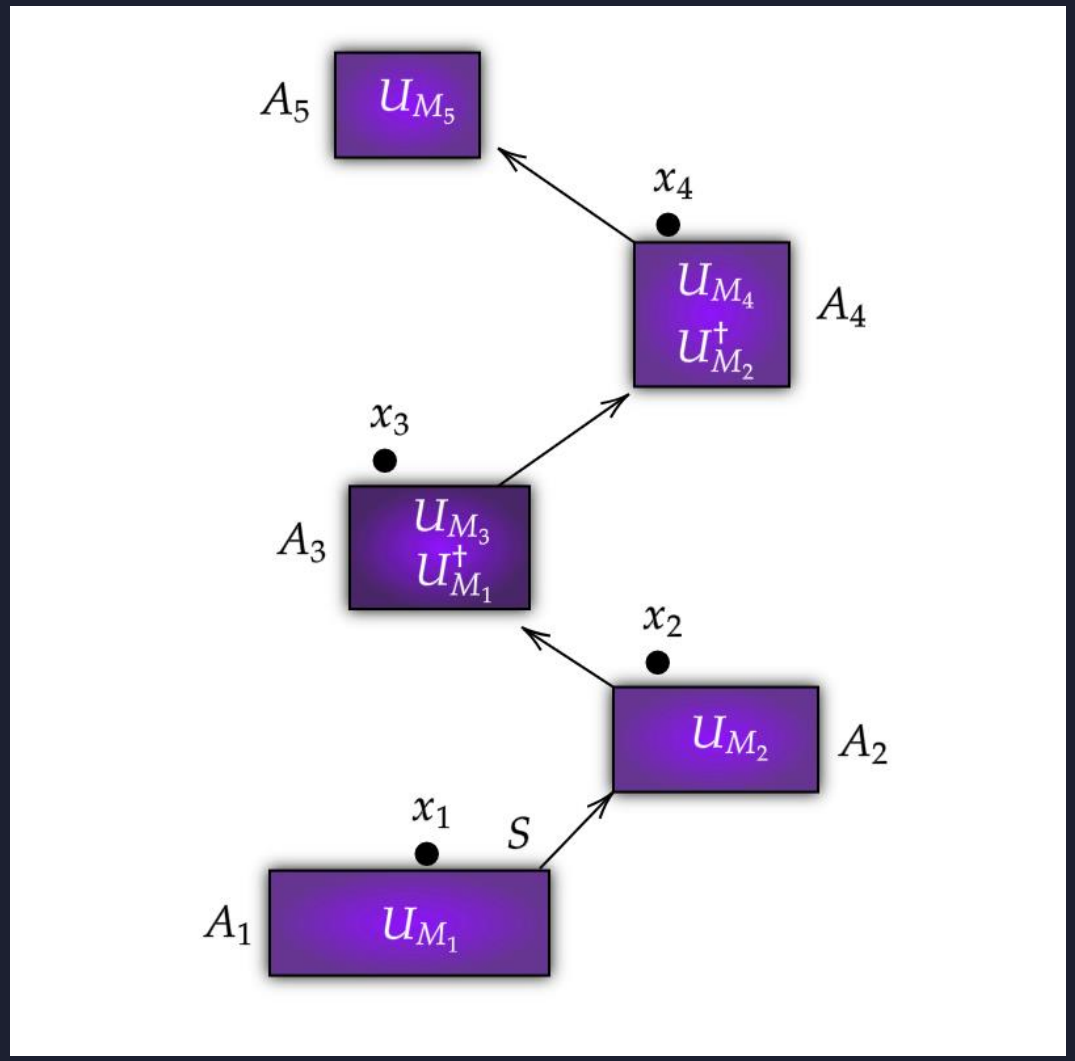

$p(0,0|4,5) = 0$
0
1
M_4
0
M_5
$p(1,1|3,4) = 0$
$p(0,1|5,1) > 0$
M_3
1
1
M_1
$p(0,0|2,3) = 0$
M_2
$p(1,1|1,2) = 0$
0

5-CYCLE WIGNER'S FRIEND PROTOCOL "CF 5-CYCLE"

To obtain context {1,5} we must commute
U_{M_5} past 4,3,2 until U_{M_1}:

- So we must replace Locality by Commutation Irrelevance
- Similar to Bell → KS noncontextuality

violates **Commutation Friendliness**

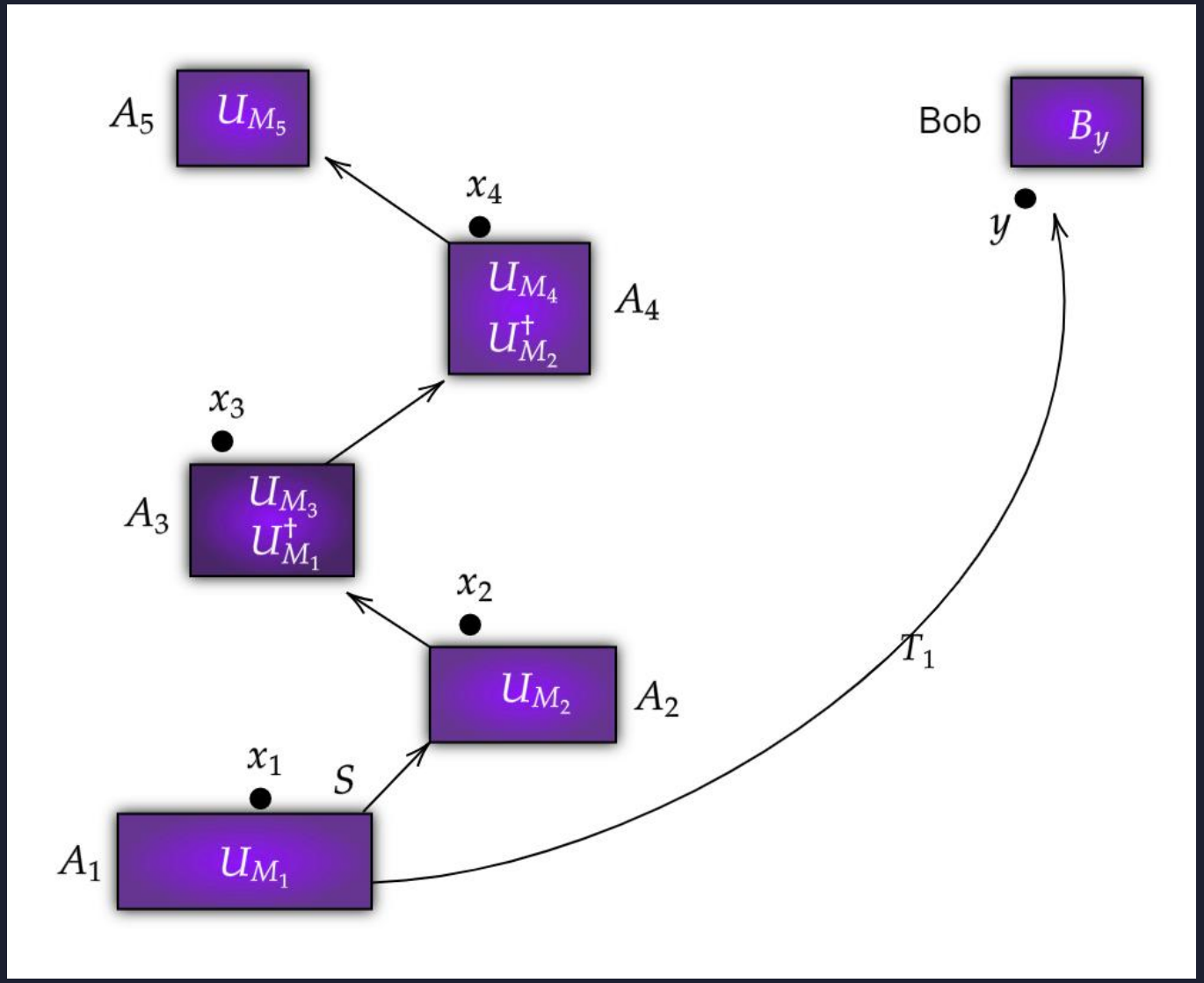


5-CYCLE WIGNER'S FRIEND + PREPARE-AND-MEASURE "LF 5-CYCLE"

Measurement Bob depends on choice y

- ❑ y = 0 measure outcome a1
  - (by Local Agency also gives conditions on case y=1,b=+
- ❑ y = 1 measure in +,- basis:
  - If outcome = +: U_{M_1} is undone and other 5-cycle contexts are obtained

violates Local Friendliness (using possibilistic contextuality) as p(a1,a2,a3,a4,a5 |x_{1-4}=0,y=1,b=+) is global NC distribution (which cannot exist)



A LOCAL FRIENDLINESS PARADOX BASED ON THE PERES-MERMIN SQUARE

= state-independent contextuality +

Wigner's friends

CONTEXTUALITY AND NONLOCALITY: PERES-MERMIN MAGIC SUARE

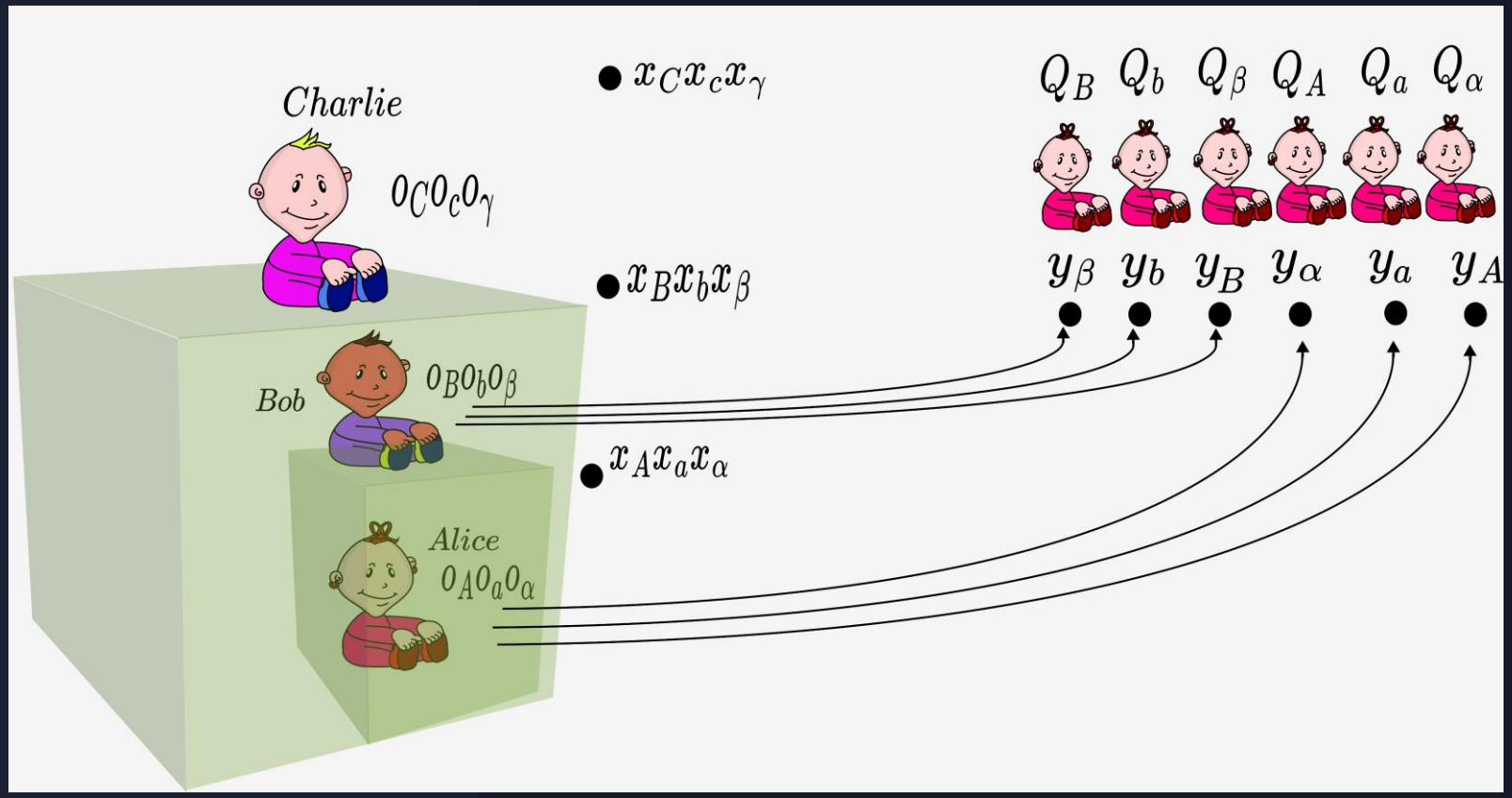
$$\begin{bmatrix} A & a & \alpha \\ B & b & \beta \\ C & c & \gamma \end{bmatrix}$$

Outcomes in {1,-1}

$$\langle Aa\alpha \rangle = 1, \quad \langle Bb\beta \rangle = 1, \quad \langle Cc\gamma \rangle = 1,$$
$$\langle ABC \rangle = -1, \quad \langle abc \rangle = -1, \quad \langle \alpha\beta\gamma \rangle = -1.$$

THE LF-PERES-MERMIN SCENARIO

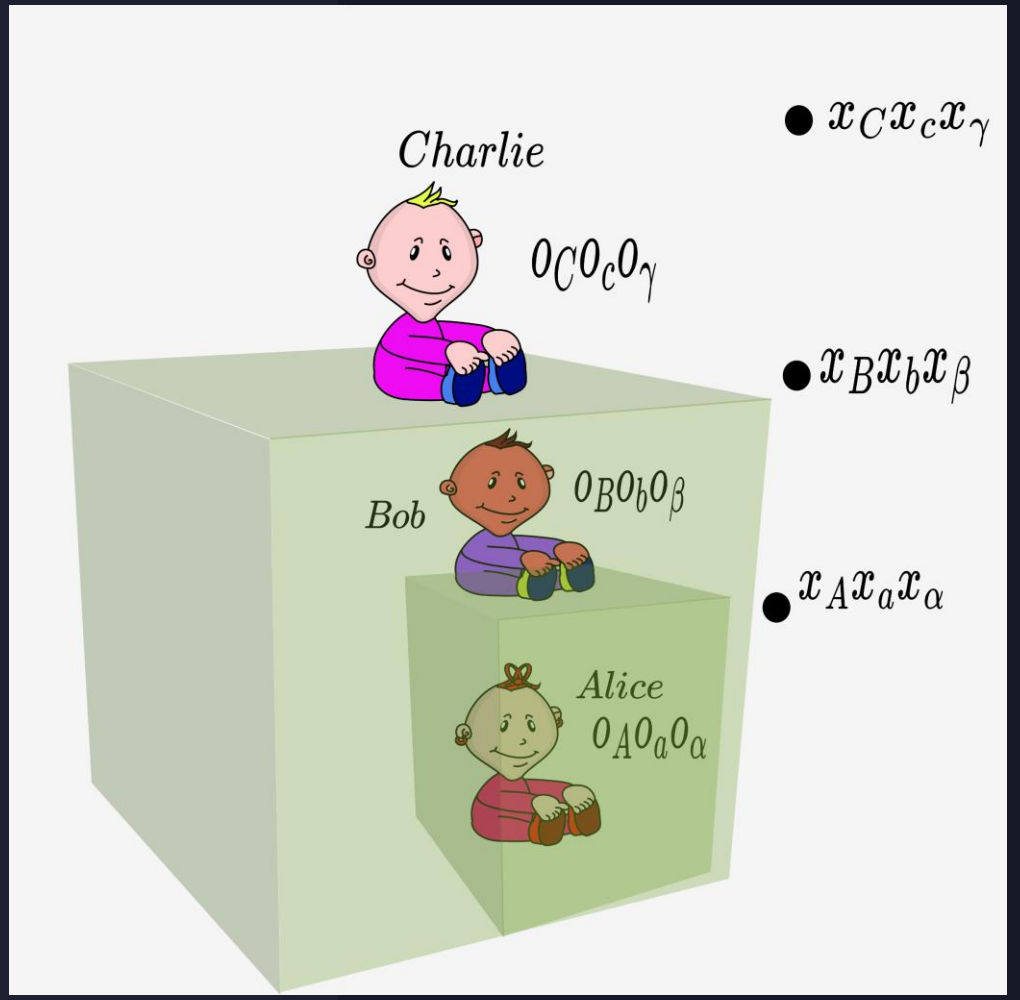
- violates Local Friendliness
- State-independent!



THE CF-PERES-MERMIN SCENARIO

What if no additional prepare-and-measures?

- Violates Commutation Friendliness
- State-independent!



LOCAL FRIENDLINESS VS. THE GHZ—FR PARADOX

GHZ–FR truth no-go theorem	
possibilistic Born rule	A classical agent can never experimentally disprove the possibilistic Born rule by gathering outcomes of measurements, possibly performed by other agents.
Universality of Quantum Theory	Superobservers exist (in principle) and quantum theory is correct
Absoluteness of Observed Events (AOE)	Every performed measurement has an absolute, single-valued outcome.
Born Compatibility	Outcomes assigned per AOE to a set of measurements which can be brought together from an agent A's perspective must not be excluded by A's use of the possibilistic Born rule.

Local Friendliness no-go theorem	
possibilistic Born rule	A classical agent can never experimentally disprove the possibilistic Born rule by gathering outcomes of measurements, possibly performed by other agents.
Universality of Quantum Theory	Superobservers exist (in principle) and quantum theory is correct
Absoluteness of Observed Events (AOE)	Every performed measurement has an absolute, single-valued outcome.
Local Agency	Any intervention (i.e. choice) is uncorrelated with any set of relevant events (per AOE) outside its future light cone.

DISCUSSION AND CONCLUSION

Resolving/refining the measurement problem using Wigner's friend paradoxes?

THANK YOU
Q?

REFERENCES