

# Relative Facts, Relational Quantum Mechanics

**A brief intro**

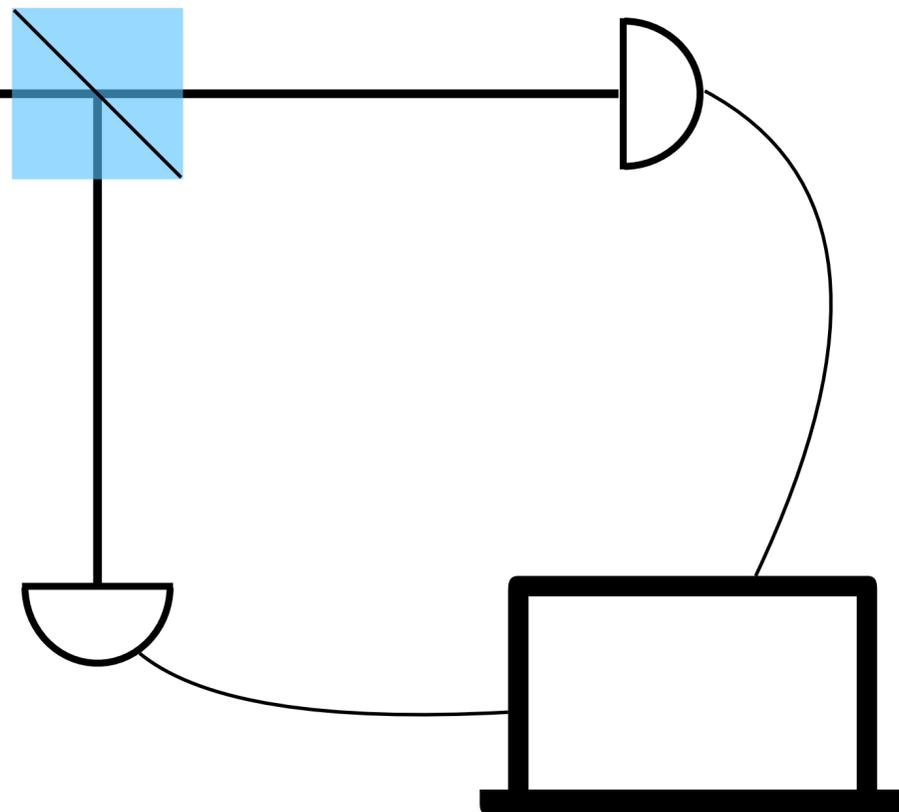
Andrea Di Biagio  
QISS 2022 Conference

# Relative Facts

## Relative Facts

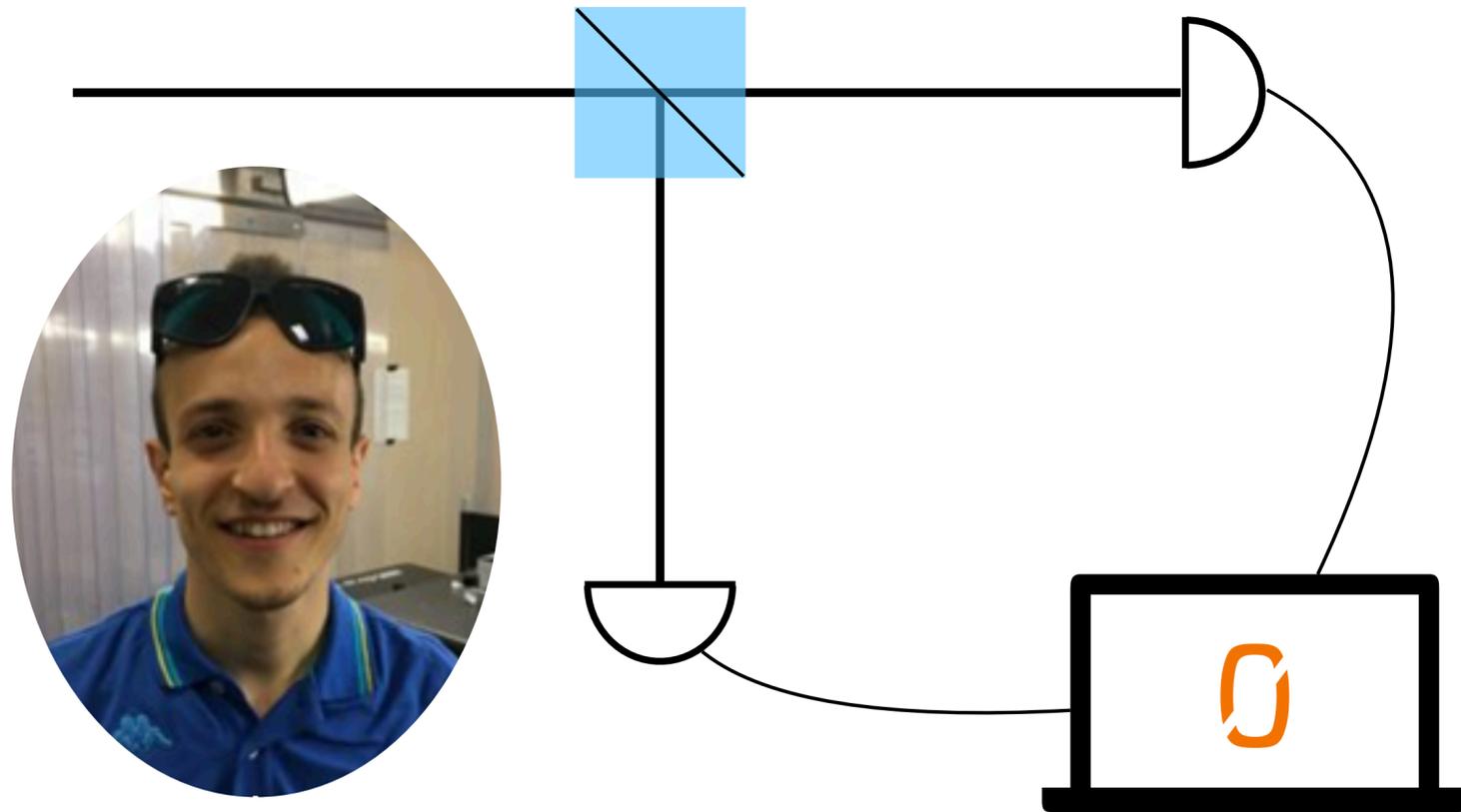
# Friends

$$\frac{1}{\sqrt{2}} |0\rangle + \frac{1}{\sqrt{2}} |1\rangle$$



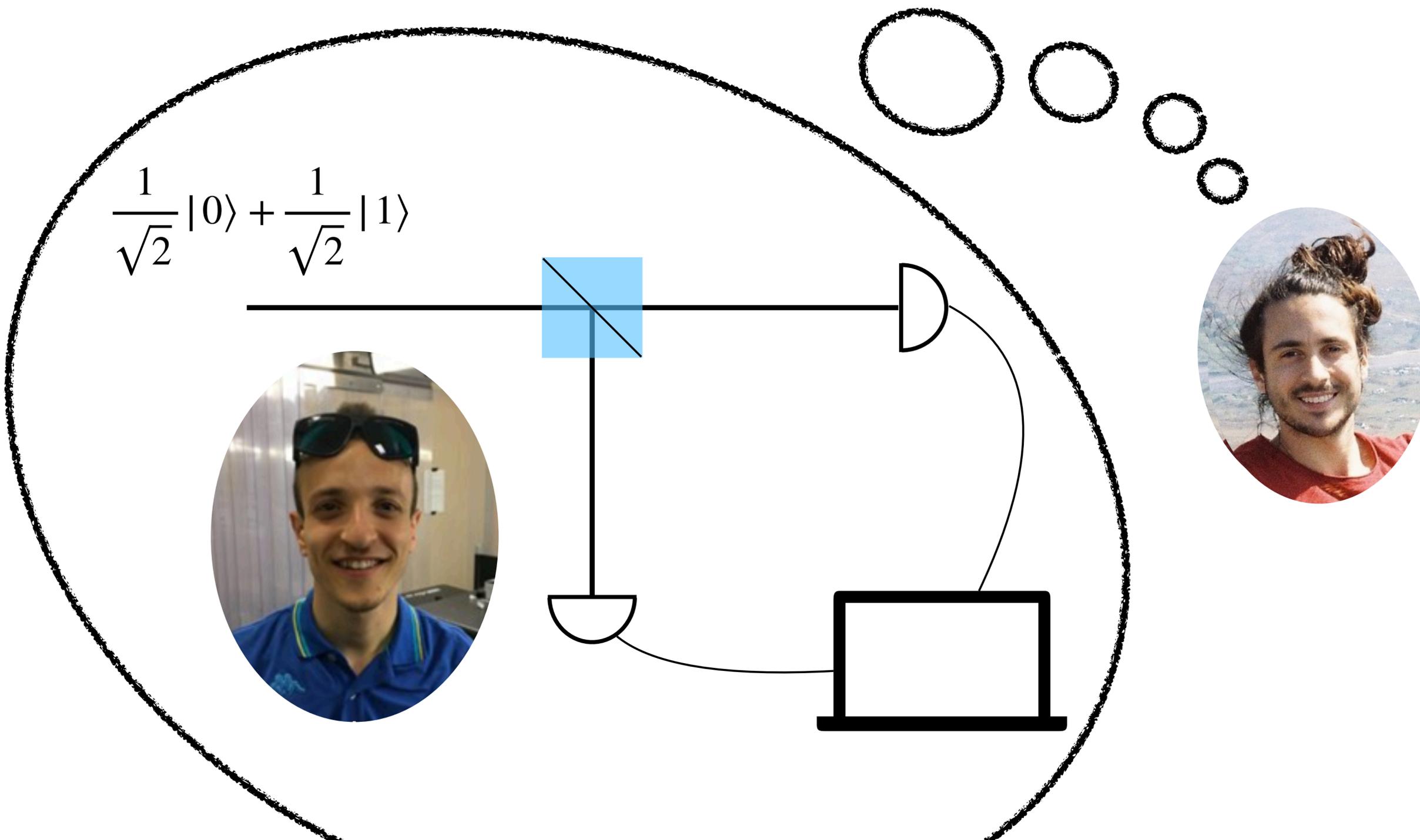
Relative Facts

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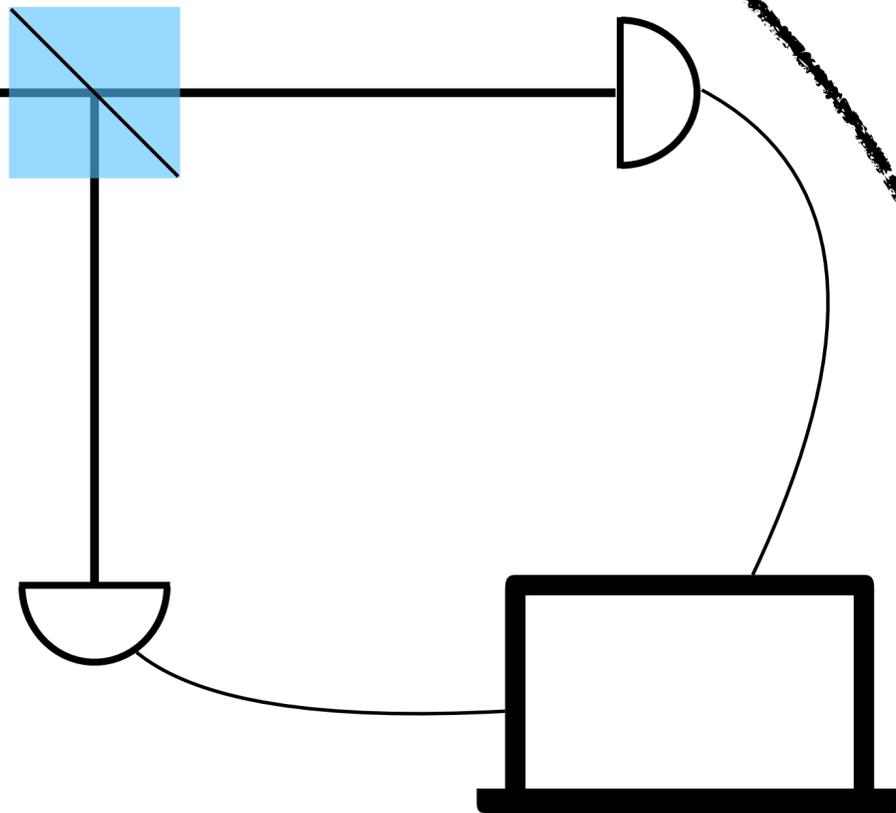
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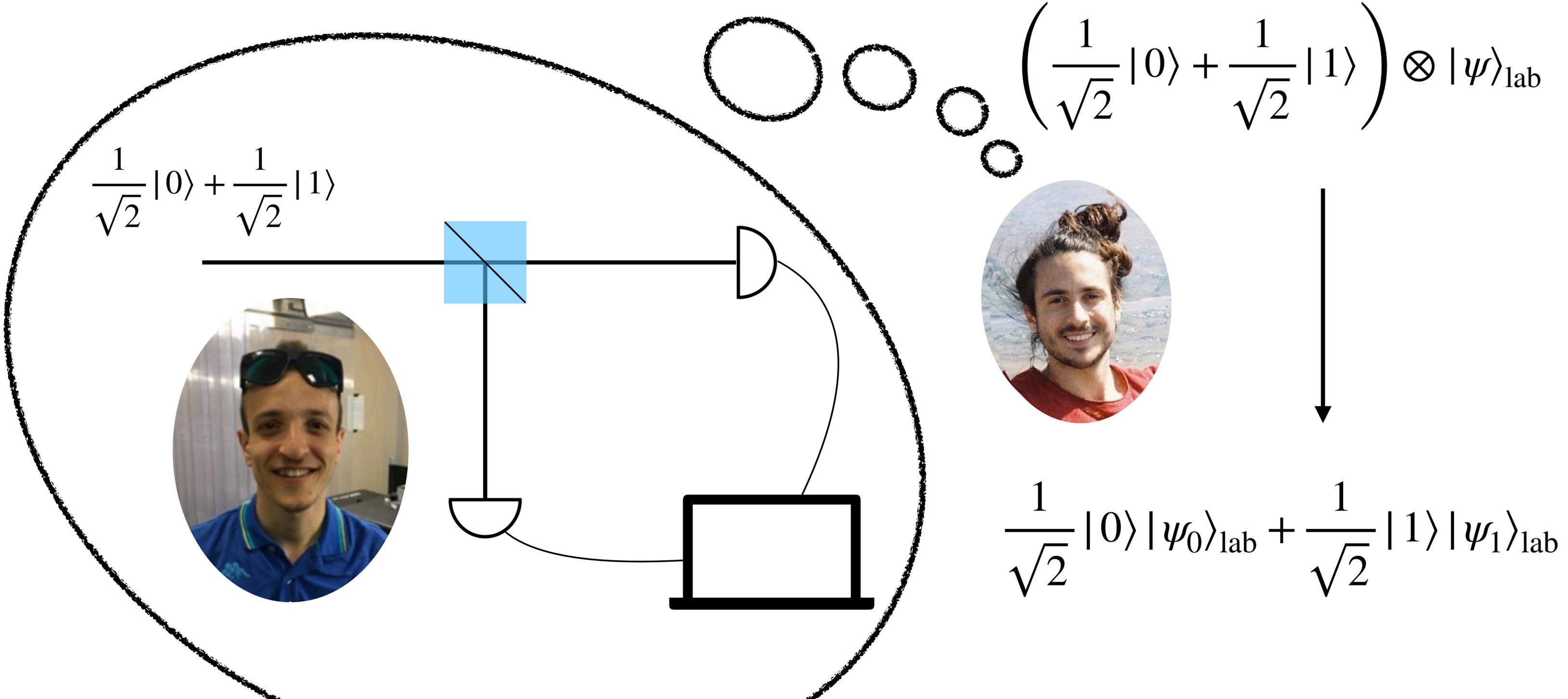


$$\left( \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle \right) \otimes |\psi\rangle_{\text{lab}}$$



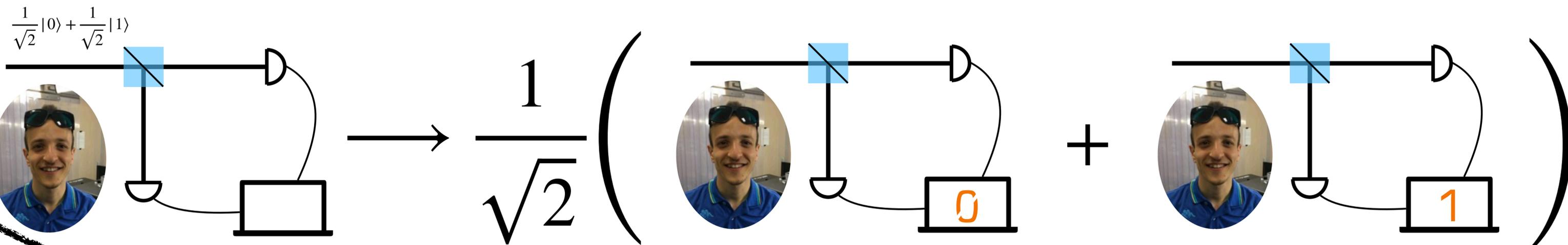
Relative Facts

# Friends



## Relative Facts

# Friends



Relative Facts

# Wigner's Friend Scenario



Relative Facts

# Wigner's Friend Scenario

is Emanuele in a superposition?



Relative Facts

# Wigner's Friend Scenario

is Emanuele in a superposition?

what does it feel like to be in a superposition?



Relative Facts

# Wigner's Friend Scenario



**is Emanuele in a superposition?**

**what does it feel like to be in a superposition?**

**but whenever I look in the lab, I see him in a definite state**



Relative Facts

# Wigner's Friend Scenario



is Emanuele in a superposition?

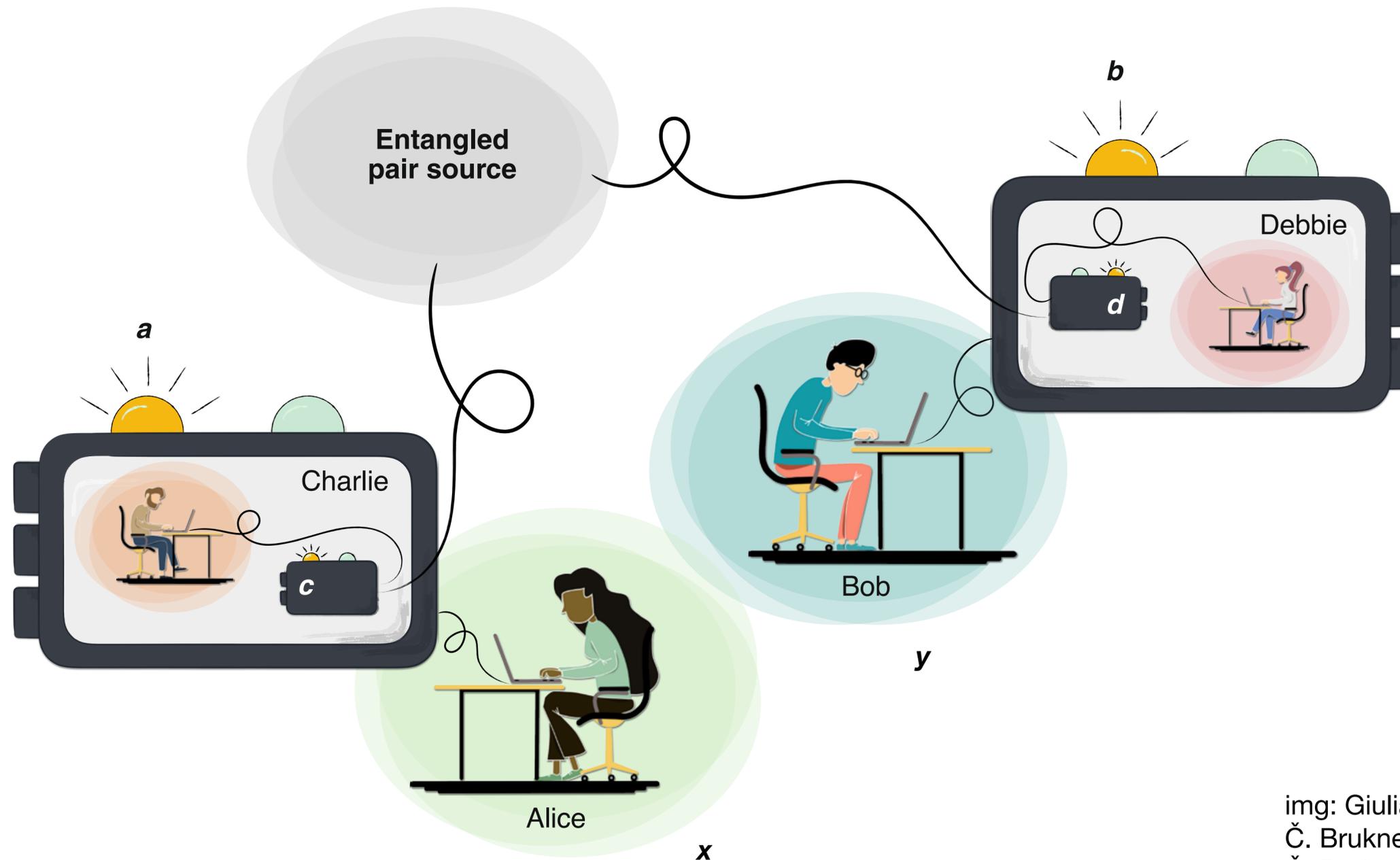
what does it feel like to be in a superposition?

but whenever I look in the lab, I see him in a definite state

it *must* just be a matter of lacking information, not a real superposition... right?



# Extended Wigner's Friend Scenario

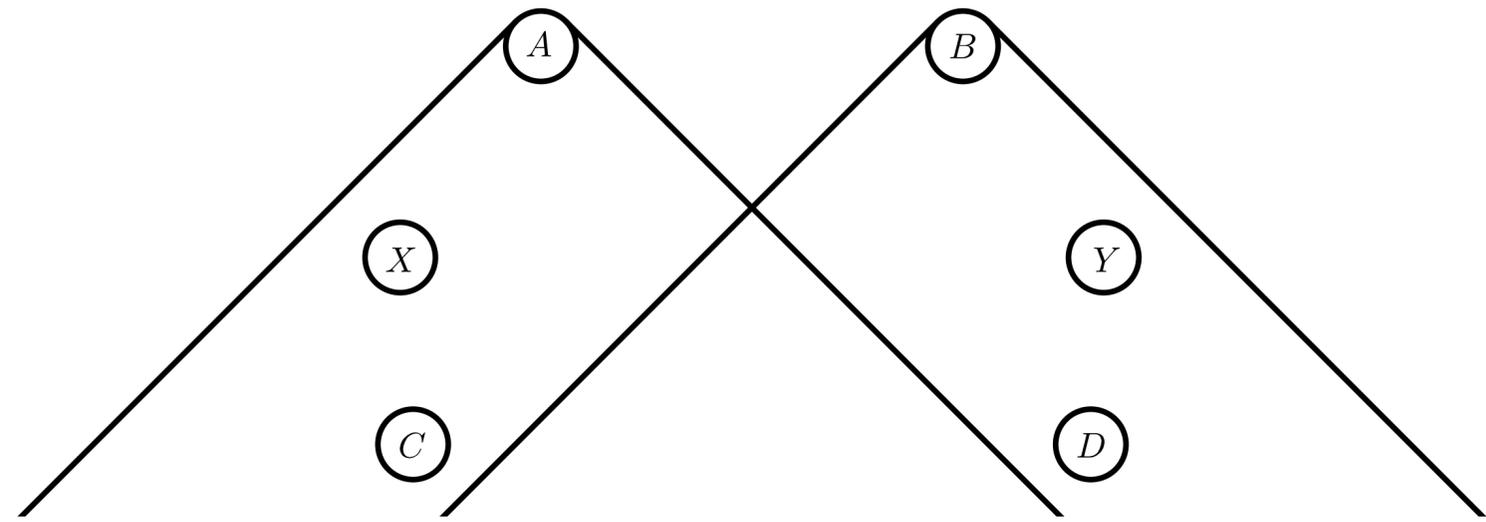


Relative Facts

# A no-go theorem

Observed frequencies

$$f(ab | xy)$$



Relative Facts

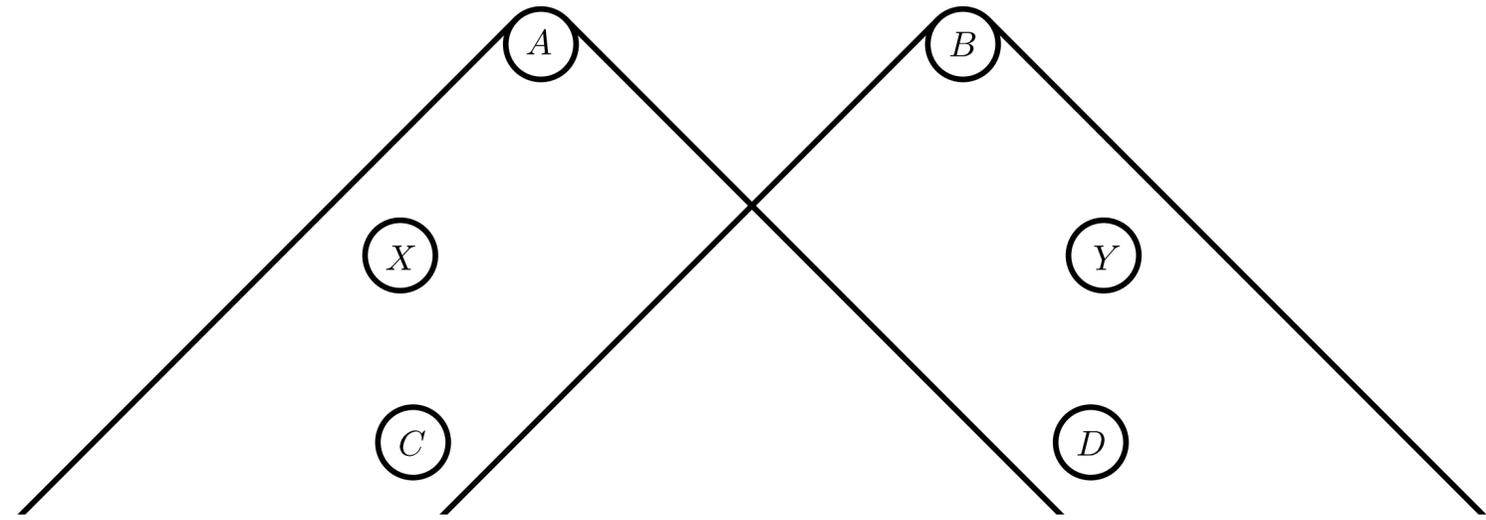
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Observed frequencies

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Absolute  
events



Relative Facts

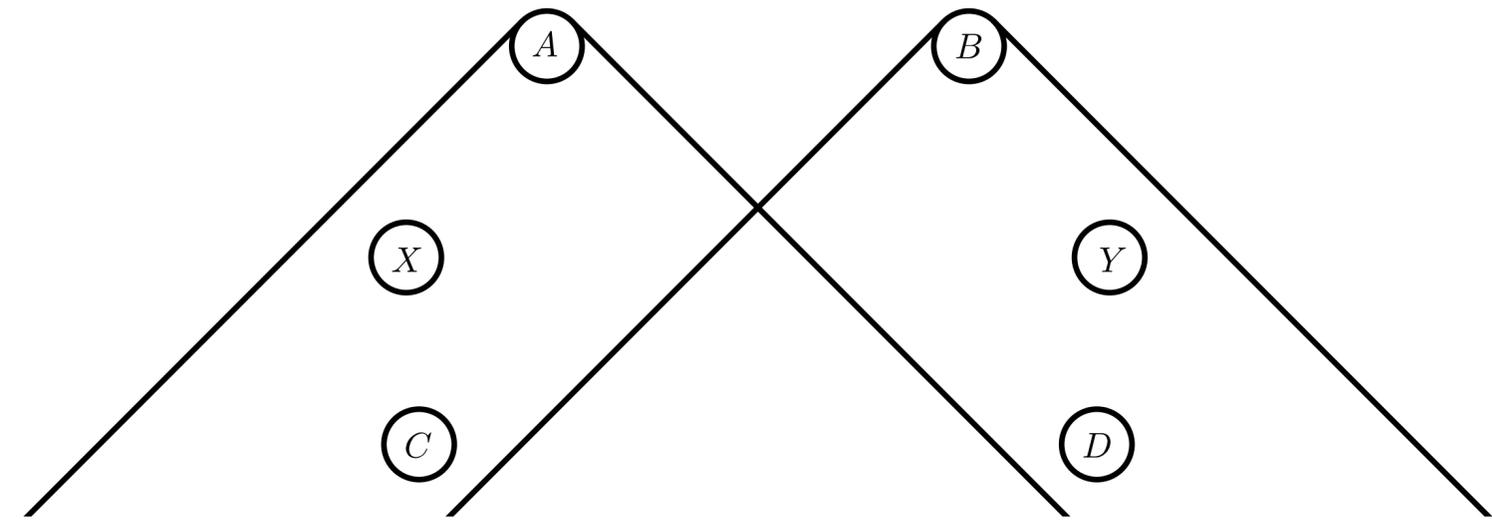
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No super-  
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Relative Facts

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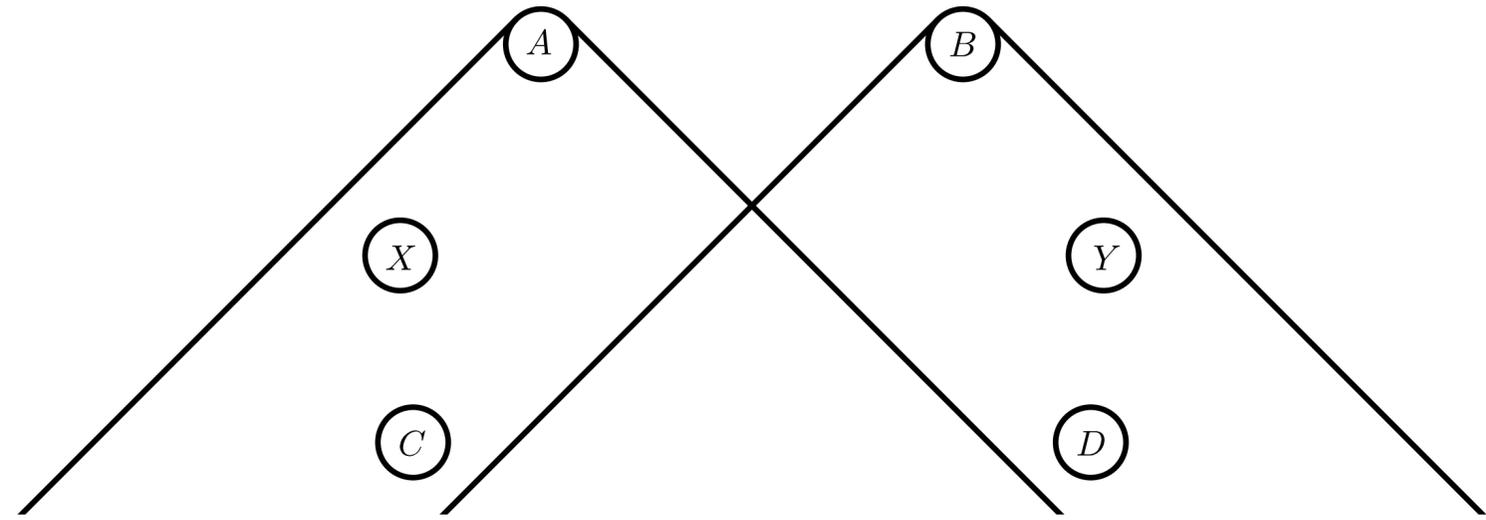
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Locality



Relative Facts

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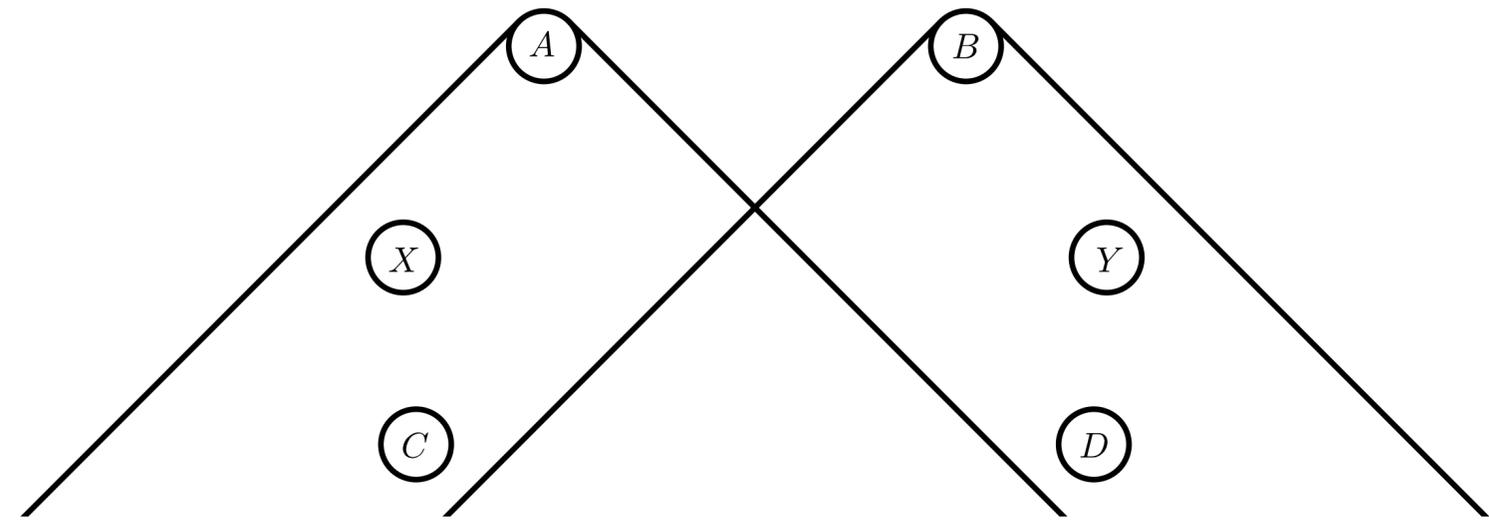
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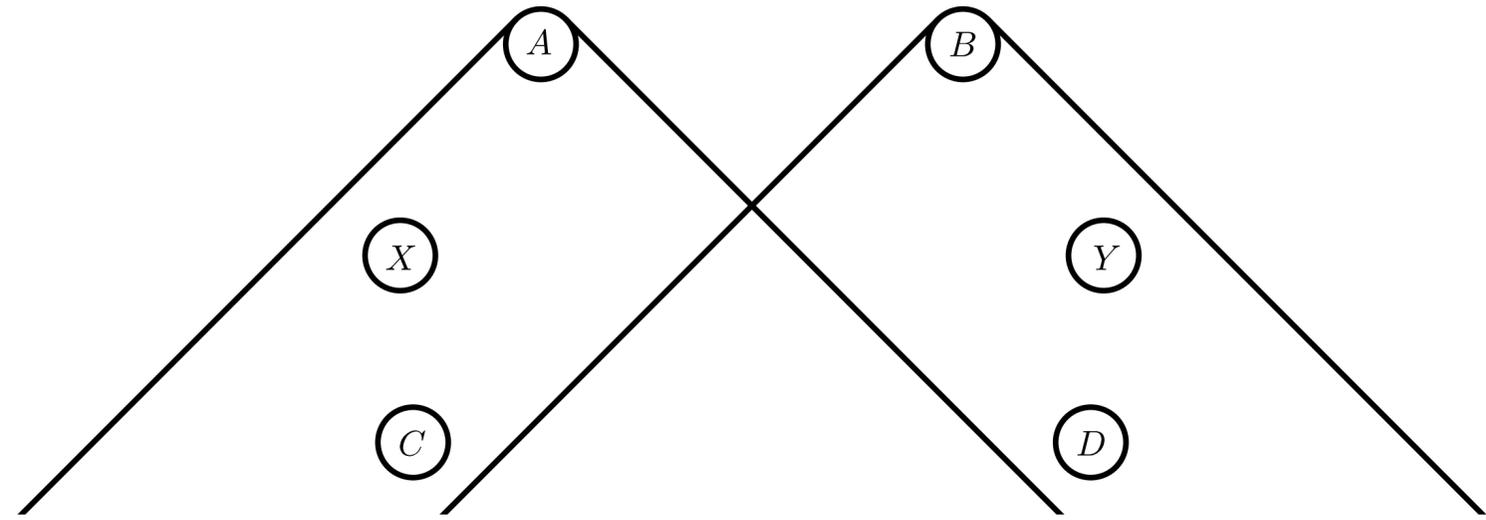
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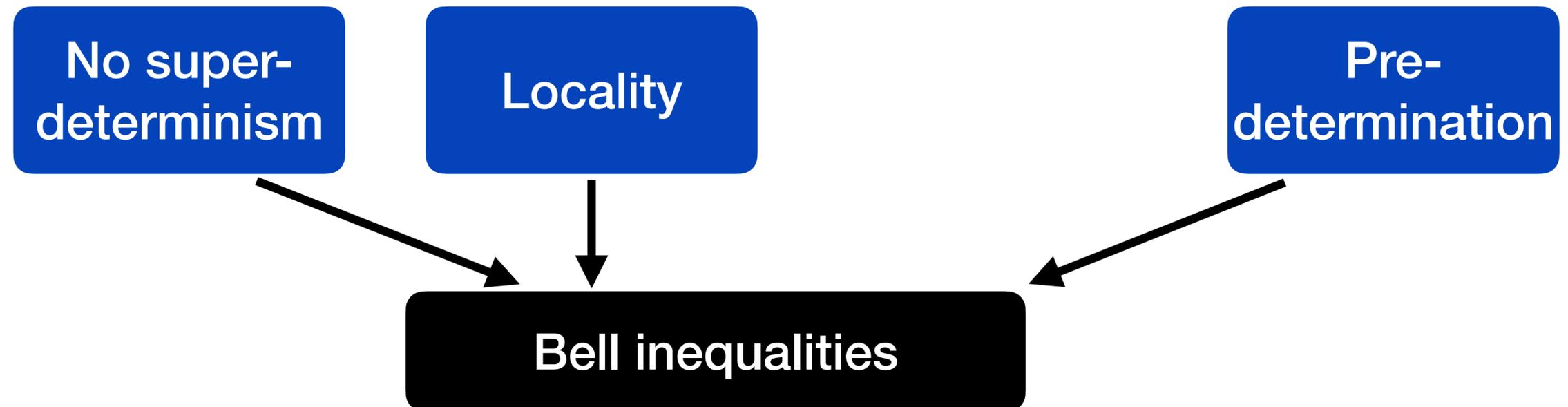
Incompatible with QM!



Relative Facts

# Comparison with Bell

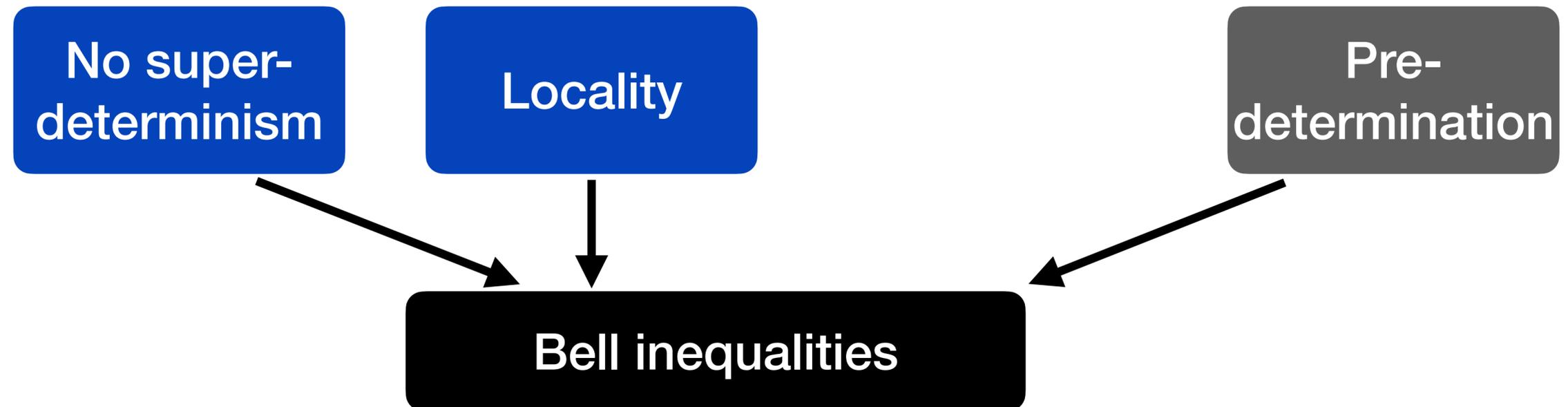
**Bell 1964**



Relative Facts

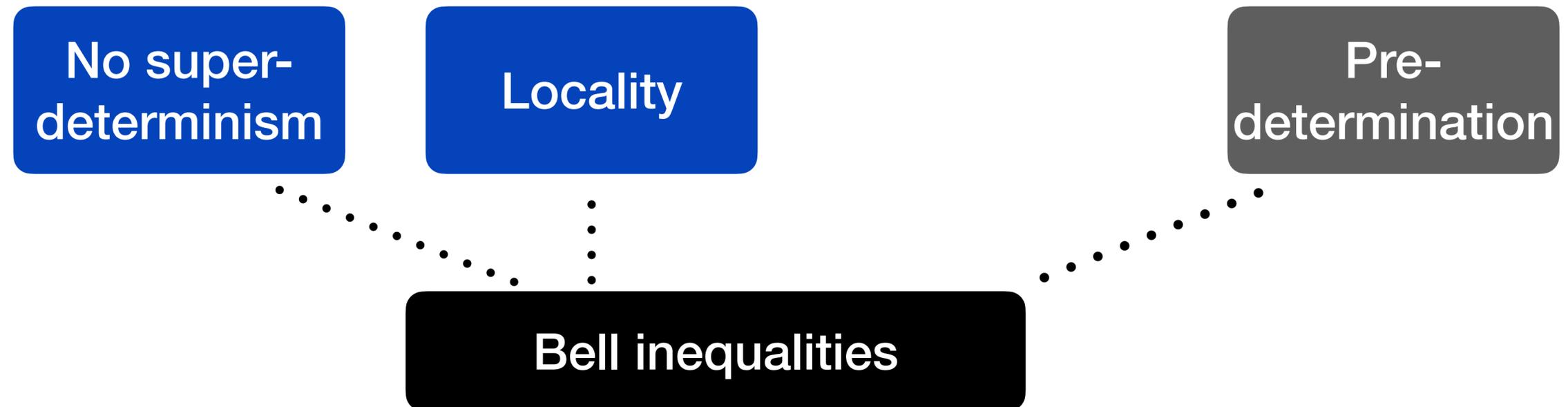
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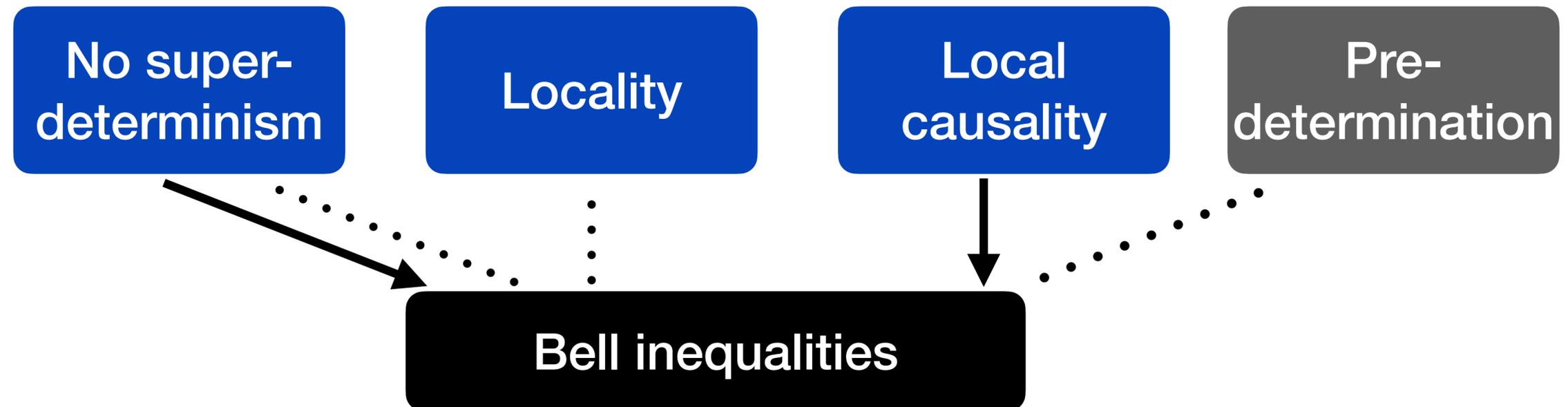
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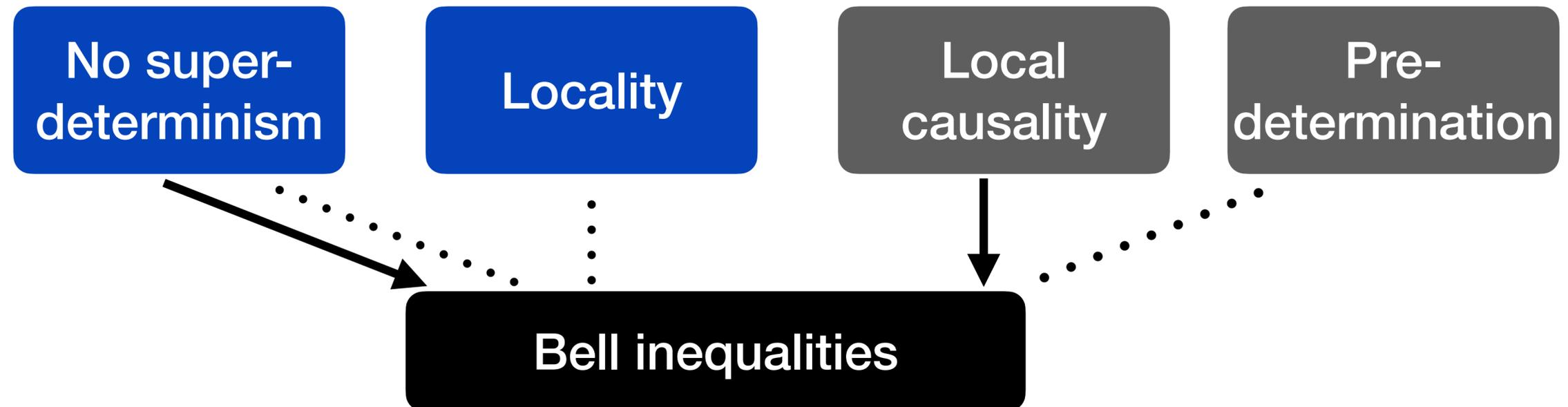
**Bell 1976**



Relative Facts

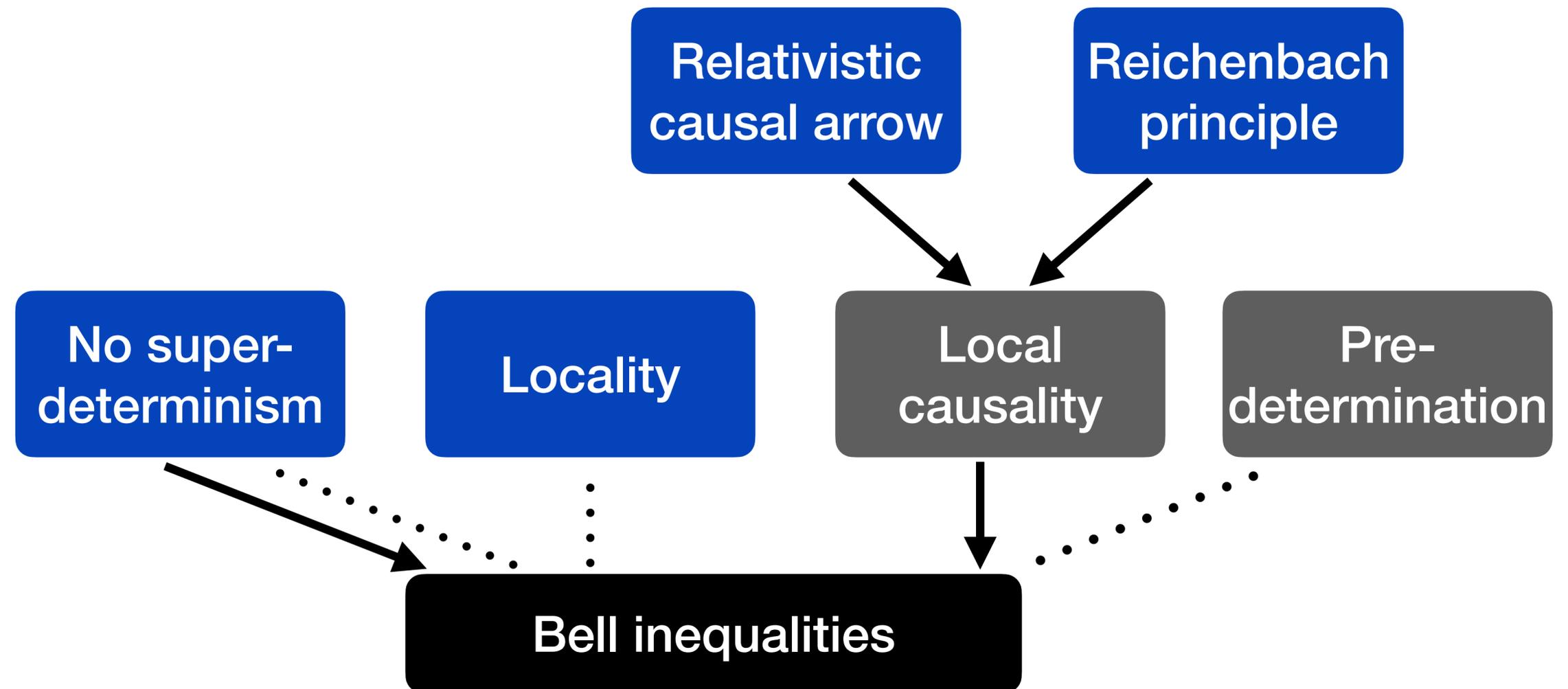
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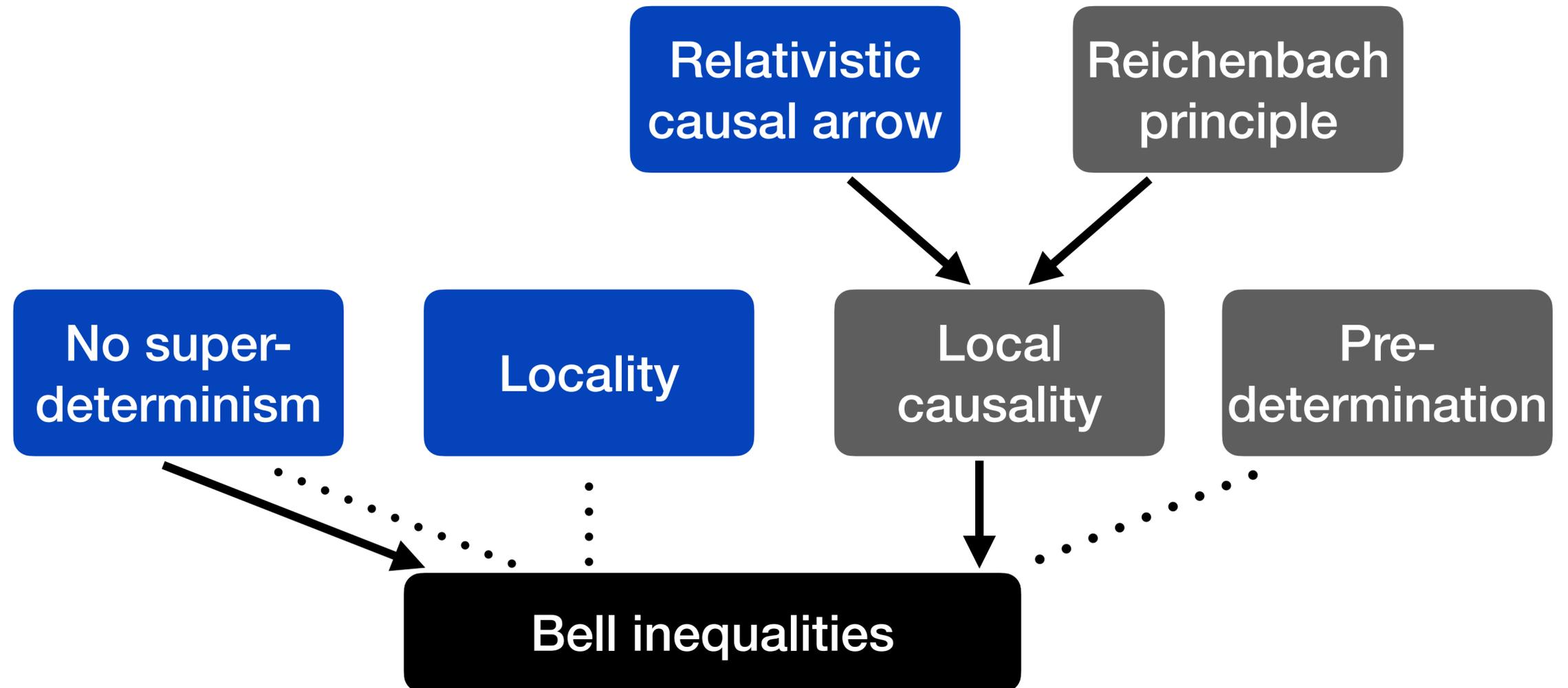
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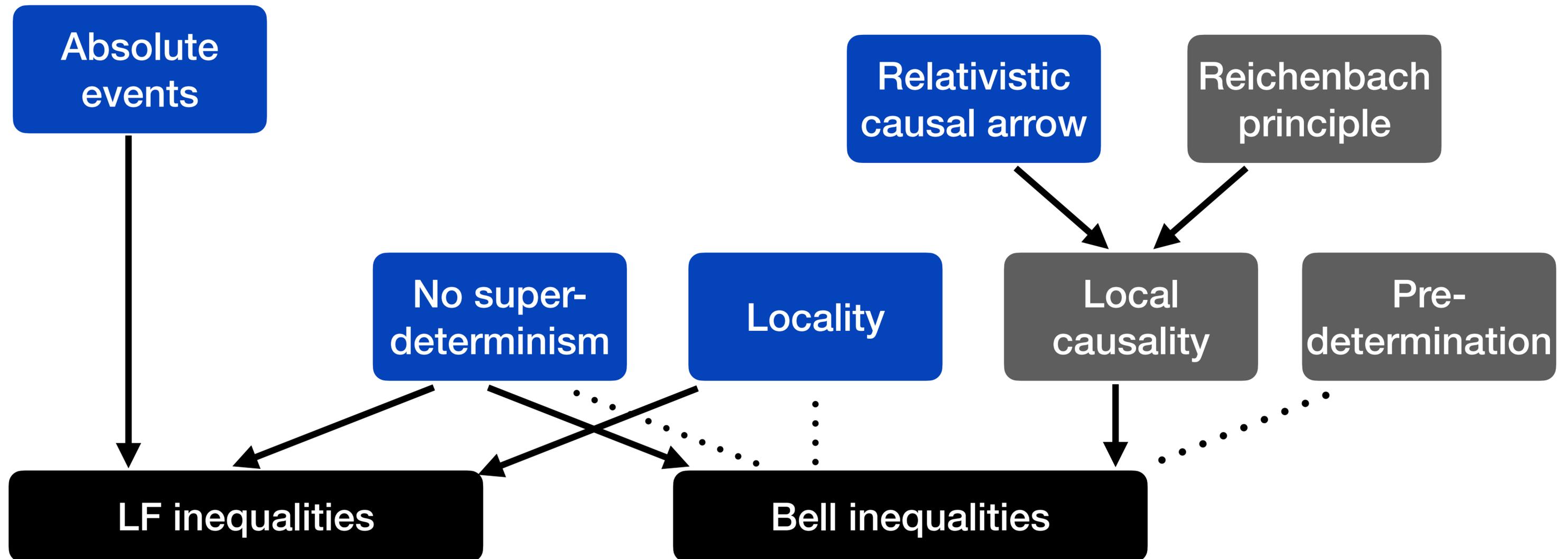


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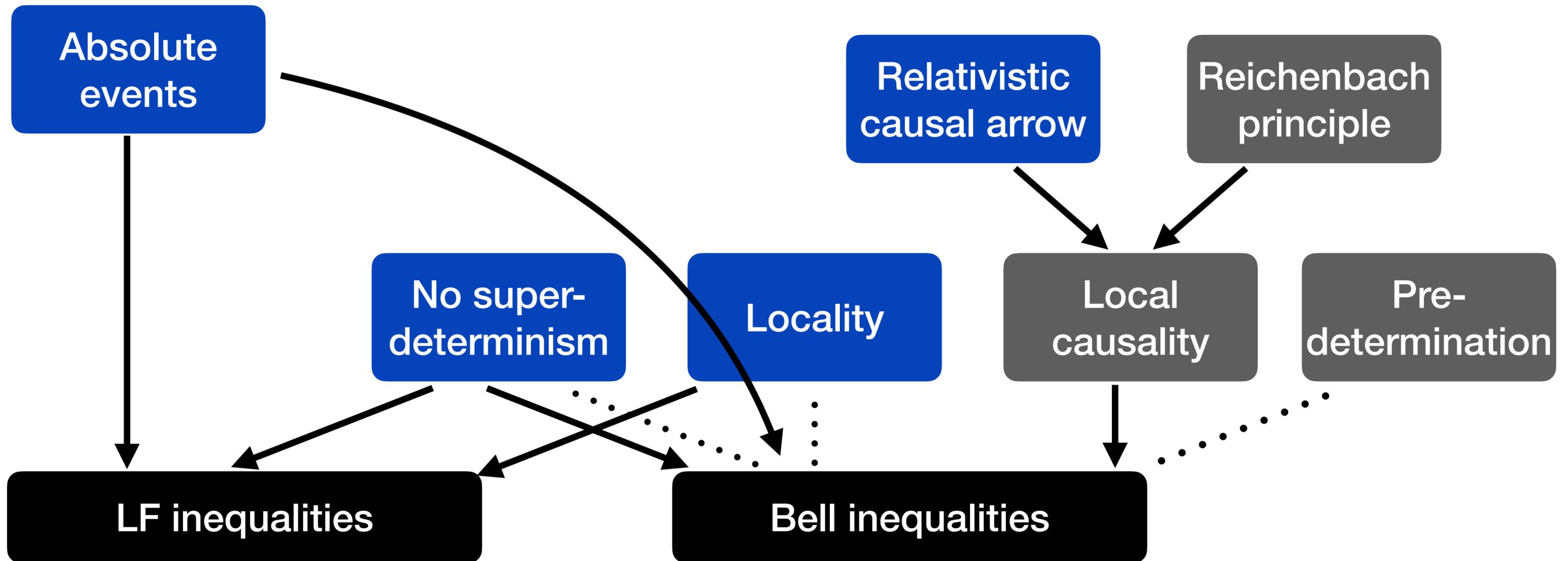
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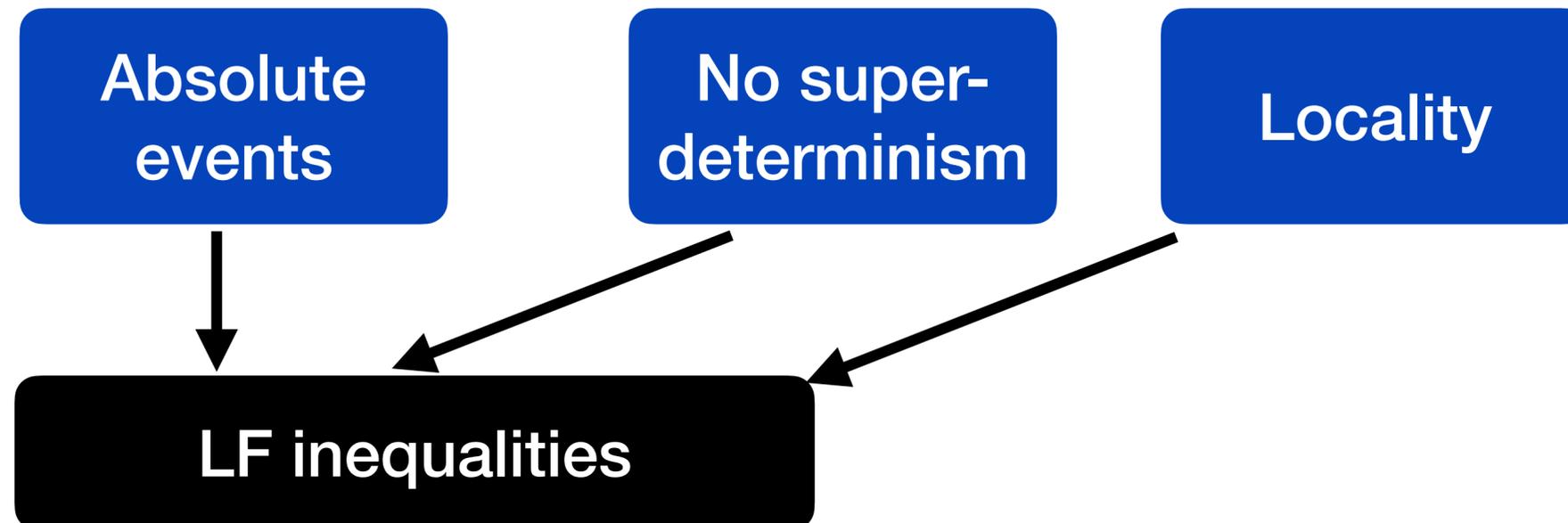
# How to cope

No-interpretation interpretation not good anymore

Modify QM: Spontaneous collapse, fundamental observers

Bohmian mechanics solves this and Bell the same way

Superdeterministic theories too



Relative Facts

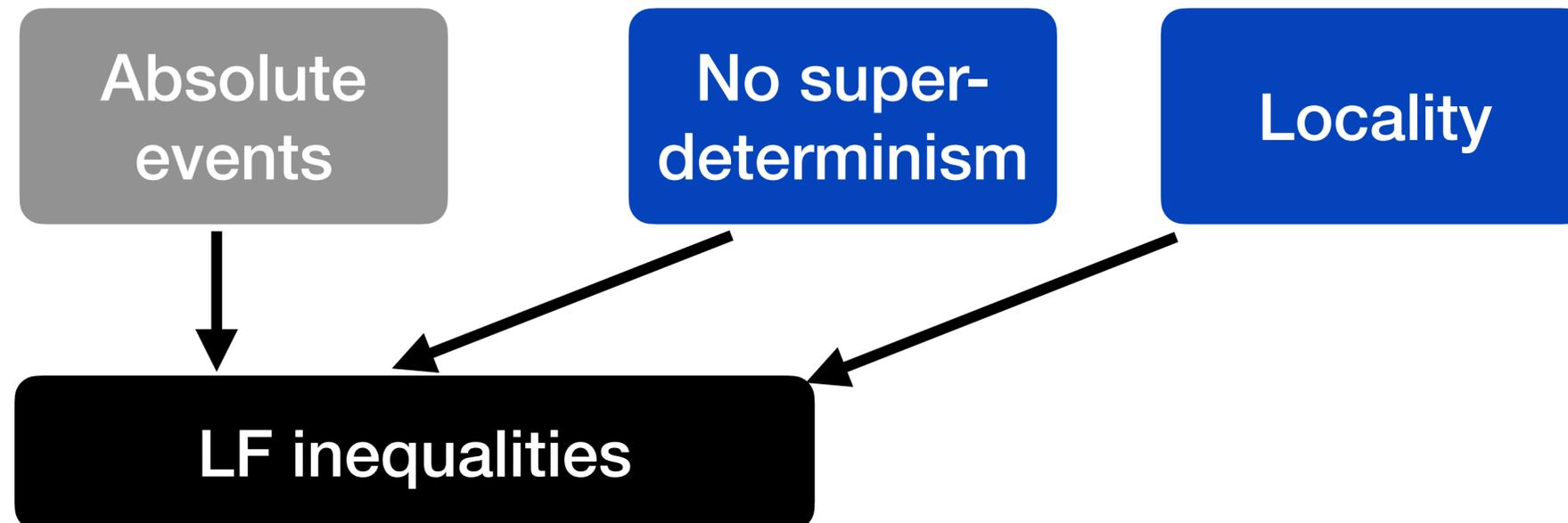
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Accept relative facts!

# Relational Quantum Mechanics

# Origins

Relational quantum mechanics

[Carlo Rovelli](#)

[International Journal of Theoretical Physics](#) **35**, 1637–1678 (1996)

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deriving the formalism from a set of simple physical postulates

quantum mechanics in terms of information theory

incorrect notion: “observer-independent values of physical quantities.”

Relational Quantum Mechanics

# Motivations

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# Motivations

- **No need to modify QM:** unitary evolution and Born rule are both correct
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- **Naturalism:** no fundamental role of observers or conscious agents
- **No inaccessible realities:** no hidden variables, or parallel worlds
- **Relativity and time-symmetry**

# Main ideas

**When two systems interact, variables take values, aka facts**

**The quantum state is assigned based on these facts, and used to compute probabilities of other facts.**

**Relative values, aka *relative facts*.**

**A third system infers an entangled state, but no facts relative to them.**



# Relative facts

$$P(a | b) = |\langle a | b \rangle|^2$$

# Relative facts

$$P(a) = \sum_b P(a | b)P(b)$$

# Relative facts

$$P(a^{(W)}) = \sum_b P(a|b)P(b^{(W)})$$

# Relative facts

$$P(a^{(W)}) \neq \sum_b P(a|b)P(b^{(F)})$$

Interference effects are a sign of the relativity of facts

# Stable facts

$$|\psi\rangle = \sum_i \alpha_i |i\rangle_S \otimes |\psi_i\rangle_E$$

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$$\longrightarrow \sigma = \text{tr}_E |\psi\rangle\langle\psi| = \sum_i |\alpha_i|^2 |i\rangle\langle i| + \mathcal{O}(\epsilon)$$

$$\epsilon = \max_{i \neq j} |\langle\psi_i|\psi_j\rangle|^2$$

# Stable facts

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$$P(a^{(W)}) \approx \sum_b P(a|b)P(b^{(F)})$$

# Stable facts

**Decoherence makes it look it as if we share facts**

**Decoherence is never complete.**

**Decoherence is relational: it depends on the couplings.**

**Systems can be in different *stability classes*.**

**Also: Issue of "cross-perspective links"**

# Some questions

1. How do we *really* make sense of relative facts?
2. Can we live without merging perspectives?
3. What is the relation with Brukner-Zeilinger, Healey, QBism, Everettian...?
4. Revise the resolution of Bell's theorems
5. GPTs, W-matrix, (QRFs) do not deal with relative facts

## References

### Relative Facts

- Č. Brukner; *A No-Go Theorem for Observer-Independent Facts*, Entropy **20**, DOI:[10/gdq8td](https://doi.org/10/gdq8td) arXiv:[1804.00749](https://arxiv.org/abs/1804.00749)
- Č. Brukner; *Facts are relative*, Nature Physics **16** DOI:[10/gp9dn7](https://doi.org/10/gp9dn7)
- K. Bong *et.al.*; *A strong no-go theorem on the Wigner's friend paradox*, Nature Physics DOI:[10/gg85dd](https://doi.org/10/gg85dd)
- H. Wiseman, E. Cavalcanti; *Causarum Investigatio and the Two Bell's Theorems of John Bell*, Quantum [Un]Speakables II (2015) arXiv:[1503.06413](https://arxiv.org/abs/1503.06413)
- E. Cavalcanti, H. Wiseman; *Implications of Local Friendliness violation for quantum causality*, Entropy **23**, DOI:[10/gm7w6p](https://doi.org/10/gm7w6p) arXiv:[2106.04065](https://arxiv.org/abs/2106.04065)

### Relational Quantum Mechanics

- C. Rovelli; *Relational Quantum Mechanics*, Int J Theor Phys **35** DOI:[10/bx4mzr](https://doi.org/10/bx4mzr) arXiv:[quant-ph/9609002](https://arxiv.org/abs/quant-ph/9609002)
- ADB, C. Rovelli; *Stable Facts, Relative Facts*, Foundations of Physics **51**, DOI:[10/gm7w6w](https://doi.org/10/gm7w6w) arXiv:[2006.15543](https://arxiv.org/abs/2006.15543)
- ADB, C. Rovelli; *Relational Quantum Mechanics is about Facts, not States: a Reply to Pienaar and Brukner*, Foundations of Physics **52** DOI:[10/gp9kww](https://doi.org/10/gp9kww) arXiv:[2110.03610](https://arxiv.org/abs/2110.03610)
- E. Adlam, C. Rovelli; *Information is Physical: Cross-Perspective Links in Relational Quantum Mechanics*, arXiv:[2203.13342](https://arxiv.org/abs/2203.13342)
- J. Pienaar; *A Quintet of Quandaries: Five No-Go Theorems for Relational Quantum Mechanics*, Foundations of Physics **51** DOI:[10/gm78rg](https://doi.org/10/gm78rg) arXiv:[2108.13977](https://arxiv.org/abs/2108.13977)
- Č. Brukner; *Qubits are not observers---a no-go theorem*, arXiv:[2107.03513](https://arxiv.org/abs/2107.03513)