CHAPMAN UNIVERSITY | INSTITUTE FOR QUANTUM STUDIES

Dirty Secrets of Quantum Foundations

Matthew Leifer
Chapman University

18th August 2016

1. The problem of quantum jumps.
2. There is no Copenhagen interpretation.
3. Viable Copenhagen interpretations must be perspectival.
4. We don't agree on what the problem is.
5. The Heisenberg and Schrödiner "pictures" are not equivalent.
6. We don't agree on what "realism" means.
7. We don't agree what the assumptions of Bell's theorem are.
8. The Schrödinger's cat paradox is not the same as the measurement problem.
9. All realist theories are fine-tuned.
10. The words "classical" and "quantum" are meaningless.

The problem of quantum jumps

> If we have to go on with these damned quantum jumps, then I'm sorry I ever got involved. — E. Schrödinger[1]

- The problem of quantum jumps is that quantum physicists are always jumping to conclusions.

I need to write down a quantum state for the entire universe in order to do quantum cosmology.
The Copenhagen interpretation requires an external observer.

The many-worlds interpretation is correct. $\therefore$

[1] Quoted in J. S. Bell, "Are there quantum jumps?" in M. Bell et. al. (eds.) "John S. Bell o the Foundations of Quantum Mechanics", pp. 172–192, World Scientific 2001

There is no Copenhagen interpretation

- Supposed to refer to the views of founders like Bohr, Heisenberg, Pauli, et. al.
- These are contradictory.
- The questions we care about were not fully formulated then, so you won't find clear answers to them.
- Very different to what is written in textbooks (which is usually also self-contradictory).
- Often conflated with "shut up and calculate".

- I will show that Copenhagen-type interpretations have to be, in some sense, as crazy as many-worlds.
- The whole analysis uses the following principles:
  - *Observers observe*: We agree that certain physical systems count as observers, e.g. grad students in a physics lab. Observers experience definite outcomes in a measurement.
  - *Universality Principle*: Anything (if not everything) can be described by quantum theory. There are no fundamentally "classical" or non-quantum systems in nature.
    - $\Rightarrow$ I can arrange a situation where I describe a grad student as being in a superposition.

- According to the measurement postulates, a system in the state $|0\rangle_S + |1\rangle_S$ collapses to either $|0\rangle_S$ or $|1\rangle_S$ upon measurement.
- We can also describe the measurement process as a unitary interaction:

$$\begin{aligned} |0\rangle_S |0\rangle_M &\to |0\rangle_S |0\rangle_M & \quad |0\rangle_S |1\rangle_M &\to |0\rangle_S |1\rangle_M \\ |1\rangle_S |0\rangle_M &\to |1\rangle_S |1\rangle_M & \quad |1\rangle_S |1\rangle_M &\to |1\rangle_S |0\rangle_M \end{aligned}$$

which gives

$$(|0\rangle_S + |1\rangle_S) |0\rangle_M \to |0\rangle_S |0\rangle_M + |1\rangle_S |1\rangle_M .$$

The Orthodox/Dirac-von Neumann/Textbook interpretation

- Endorses the *Eigenvalue-eigenstate link*, which says:
  - Isolated quantum systems have objective properties.
  - If the system is in an eigenstate of the operator $\hat{A}$, then A is one of its objective properties. It's value is the corresponding eigenvalue.
  - The system has no other objective properties than these.
- The measurement problem shows that this is not self consistent:

$$|0\rangle_S |0\rangle_M + |1\rangle_S |1\rangle_M$$

has different objective properties than

$$|0\rangle_S |0\rangle_M \qquad \text{or} \qquad |1\rangle_S |1\rangle_M .$$

- *Ineffability*: Quantum states do not describe reality. They represent what we know/believe/can say, or advice, about a quantum system. Further, there is no deeper description of reality to be had. This is either because:

  1. Quantum systems literally have no properties (the moon is not there when nobody is looking).
  2. The properties of quantum systems are *ineffable* (the moon may be there but it is fundamentally impossible to represent its properties in language, mathematics, physics, pictures, etc.).

The “shifty split”

- Ineffability and universality are in tension with observers observe.
- To account for the latter, we are going to have to place a split between the (“classical”) observer and the (“quantum”) observed, but this is pragmatic rather than fundamental.
- There will be a heirarcy of levels of description depending on where we place the split.
  - An observer should place the split no lower than needed to get the correct predictions,
  - but no higher than themselves in order to account for their own experience.
- The fact that levels disagree on unperformed experiments does not matter. They are not descriptions of reality.

Copenhagen with objective states

- Claim: It is always possible to find a level that all observers can agree upon. There is an objectively correct quantum state to assign at that level at all times.

- Ruled out by universality as soon as we contemplate putting an observer in a superposition, i.e. Wigner's friend.
  - Wigner uses the state:

$$|0\rangle_S |0\rangle_F + |1\rangle_S |1\rangle_F ,$$

  - His friend must necessarily use the state:

$$|0\rangle_S \qquad \text{or} \qquad |1\rangle_S .$$

Copenhagen with perspectival states, but objective clicks

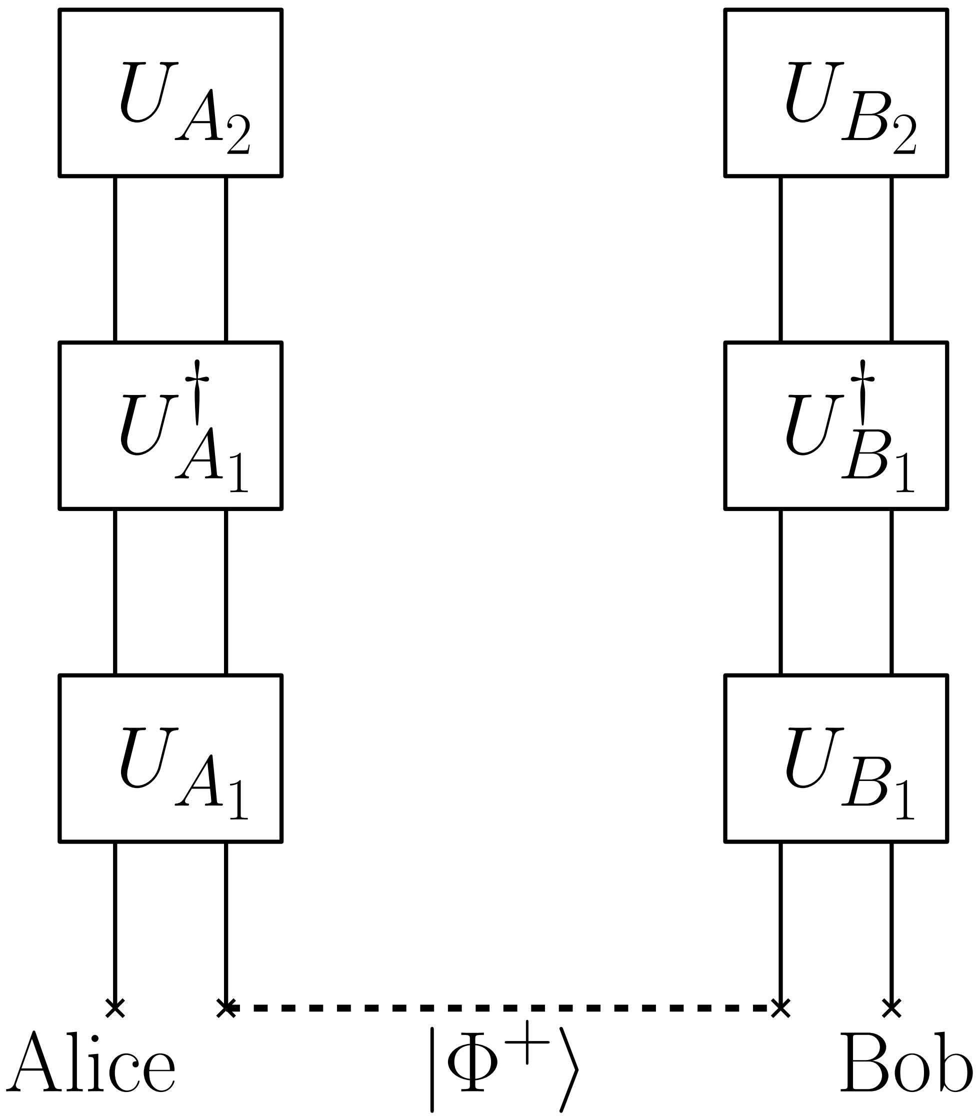
- Claim: Observers may assign completely different states (they are perspectival), but there is an objective fact of the matter about what they observe.
- When Wigner assigns the state

$$|0\rangle_S |0\rangle_F + |1\rangle_S |1\rangle_F ,$$

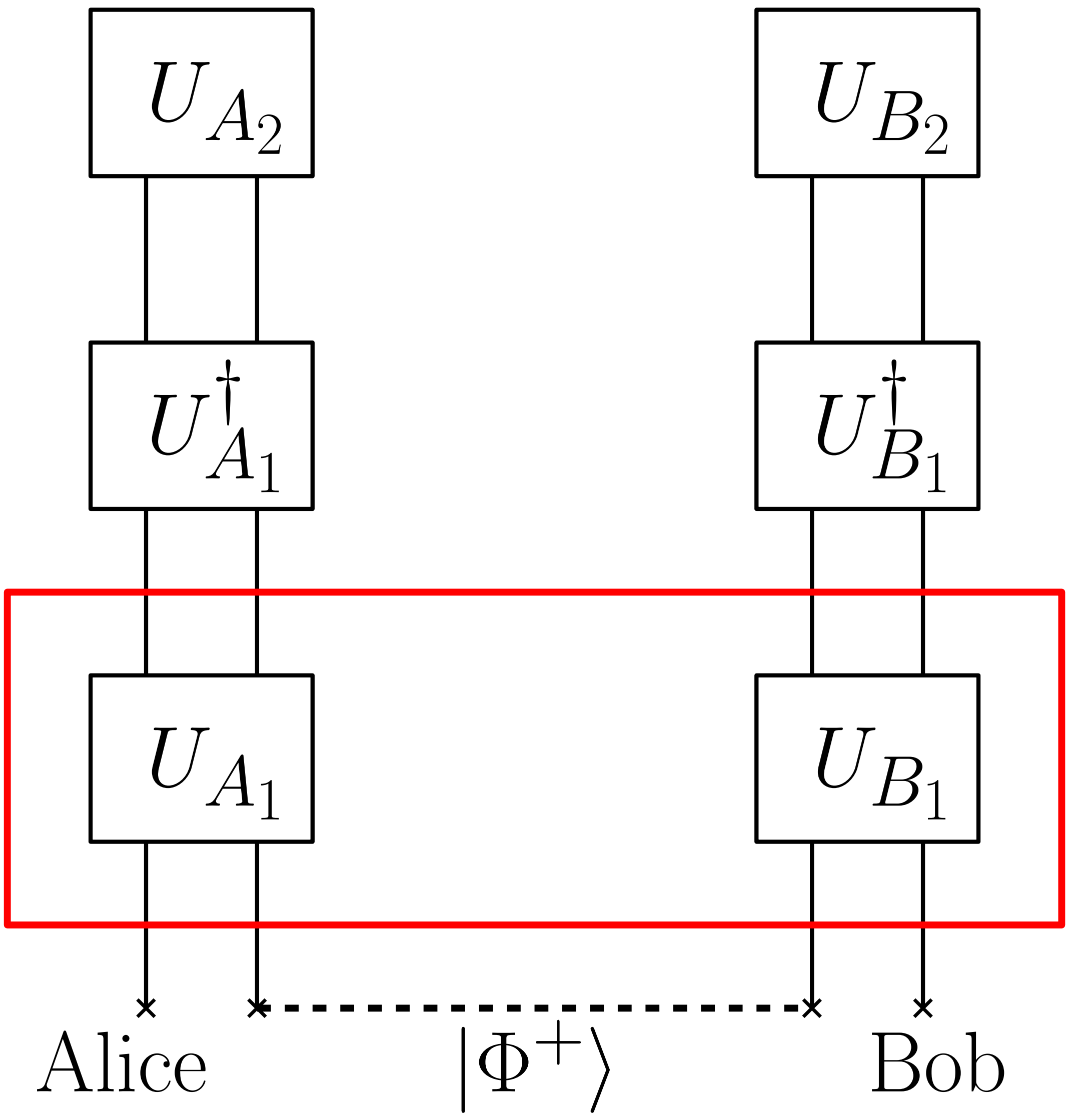
  there is an objective fact of the matter that the friend has observed a definite outcome, and what the outcome is. It is just that this is ineffable to Wigner.
- This is the ignorance interpretation of macroscopic superpositions.
- Ruled out by Frauchiger-Renner theorem[2]

[2] D. Frauchiger and R. Renner, arXiv:1604.07422 (2016).

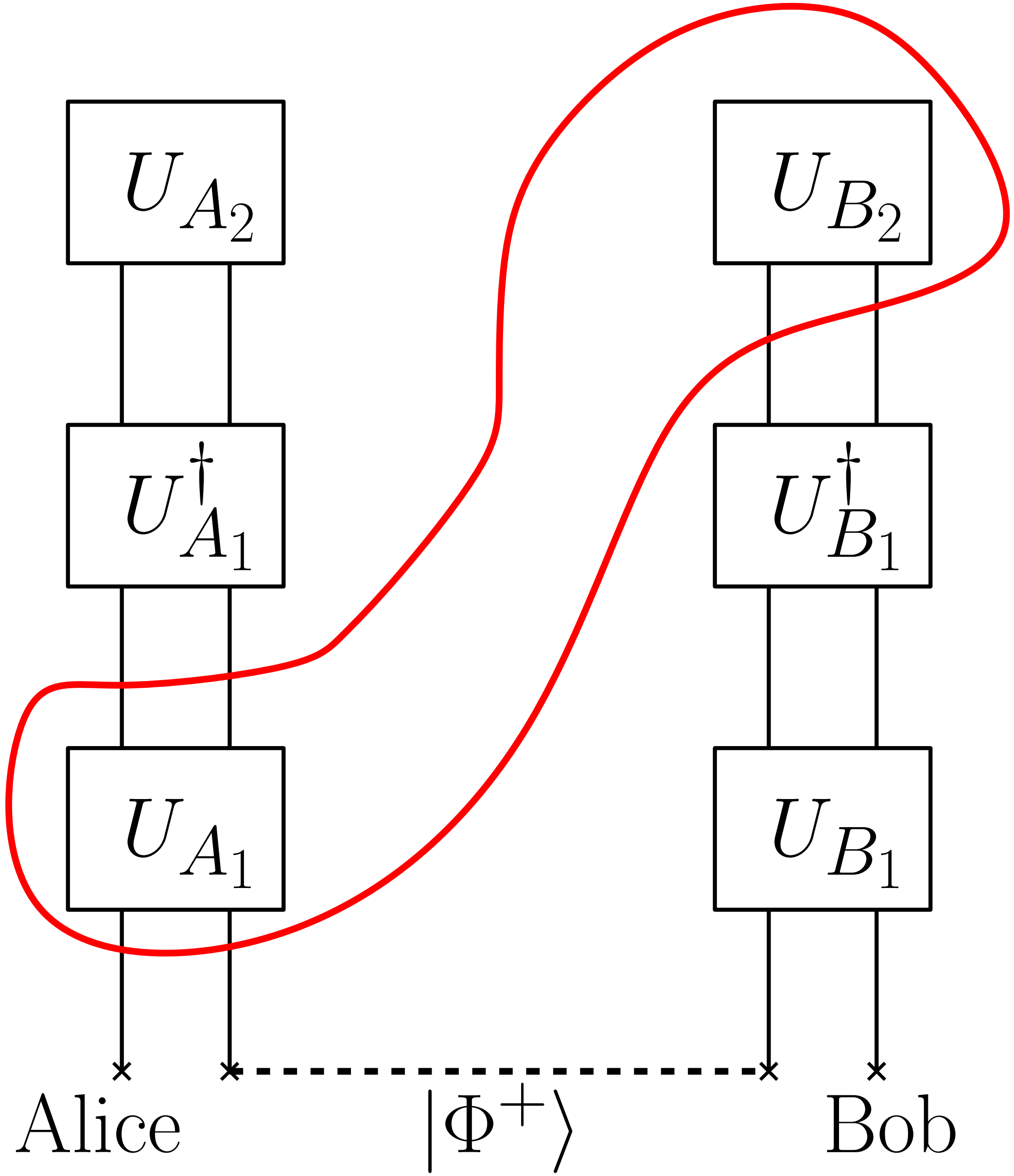
Frauchiger-Renner theorem (Masanes Version)



Frauchiger-Renner theorem (Masanes Version)

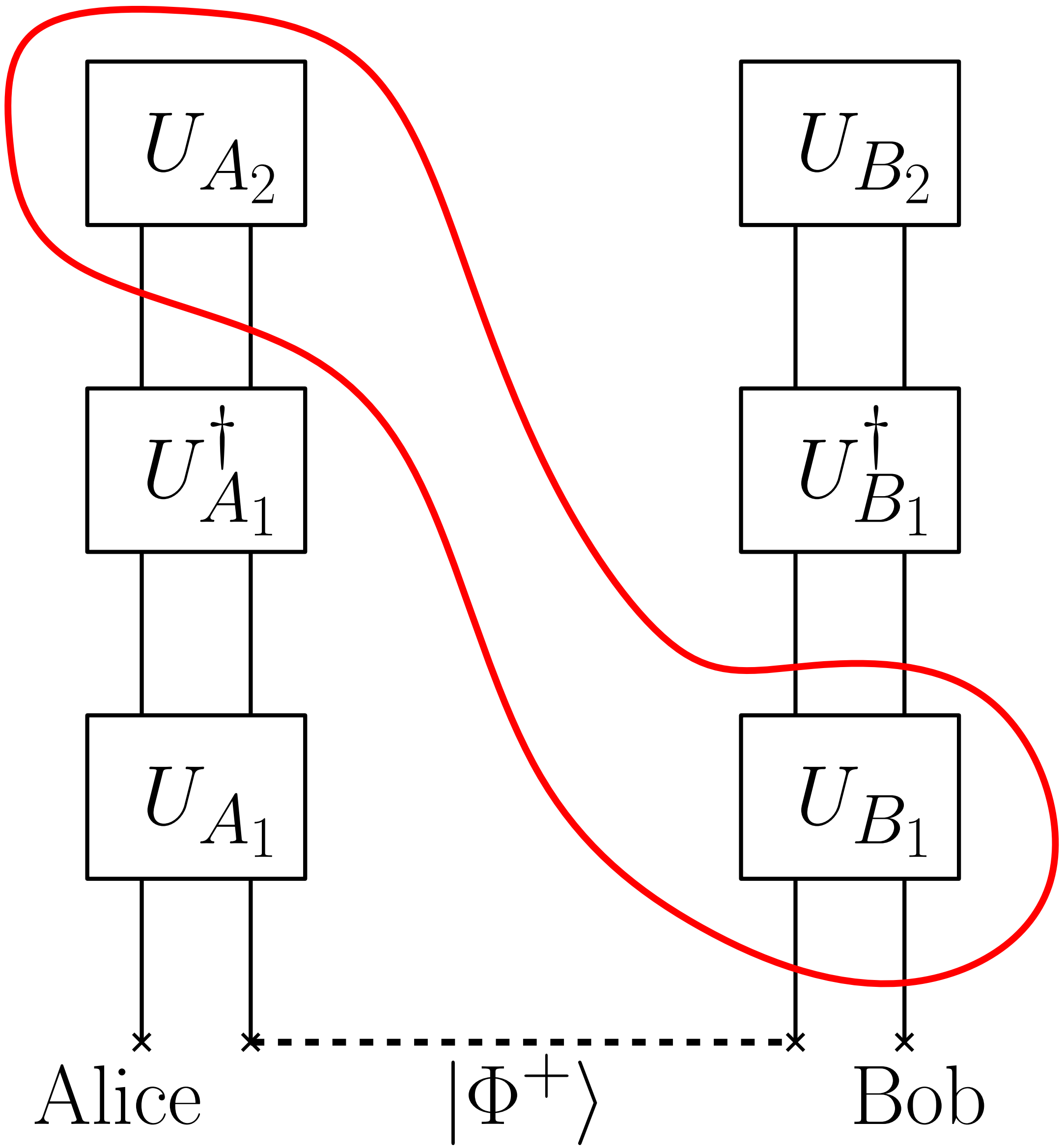


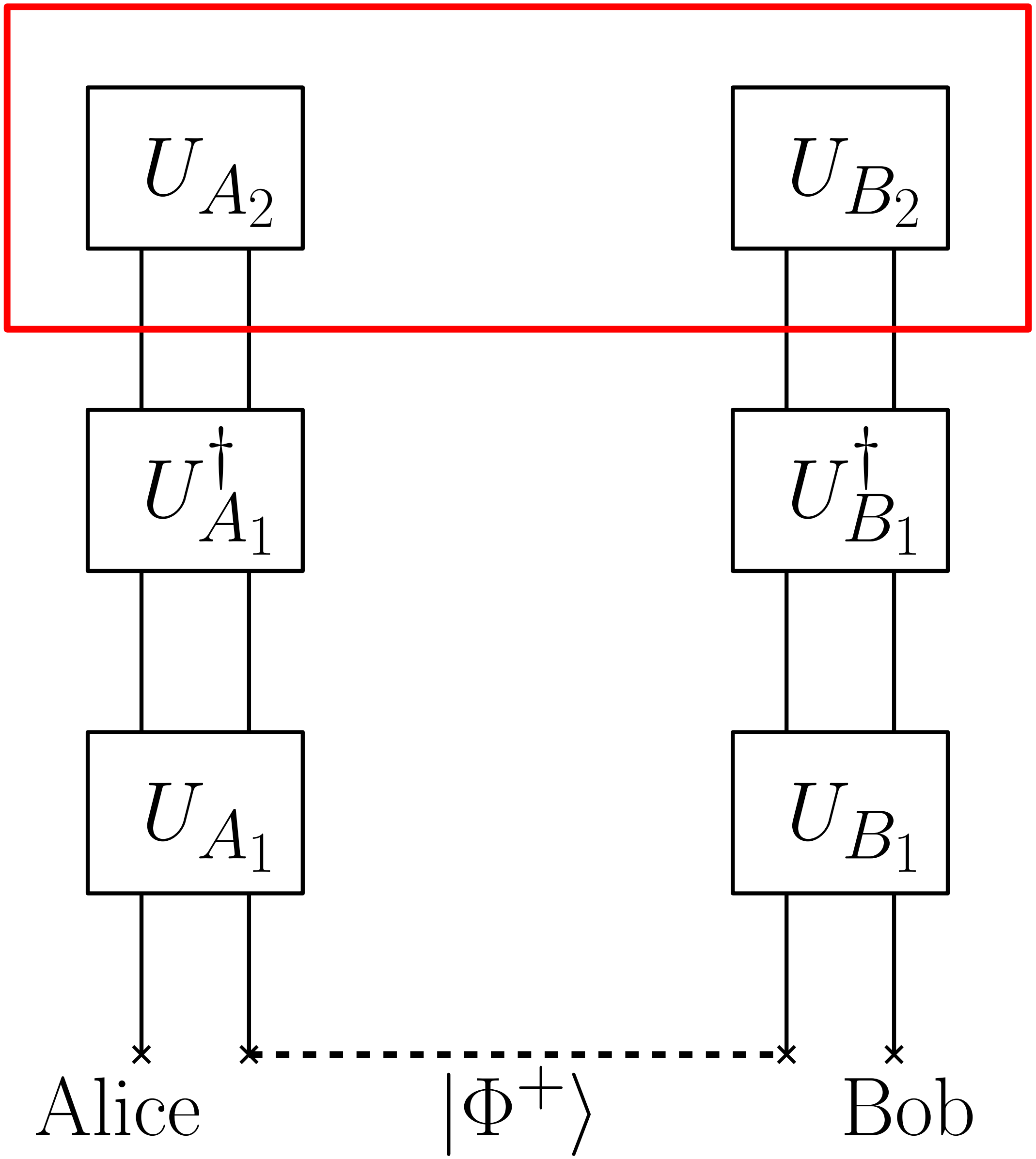
Frauchiger-Renner theorem (Masanes Version)



CHAPMAN UNIVERSITY

Frauchiger-Renner theorem (Masanes Version)




U_{A_2}
U_{B_2}
$U_{A_1}^{\dagger}$
$U_{B_1}^{\dagger}$
U_{A_1}
U_{B_1}
Alice
$|\Phi^+\rangle$
Bob

Fully perspectival Copenhagen

- When Wigner places his friend in superposition, there is a fact of the matter for the friend about what they have observed. However, there is no fact of the matter for Wigner. It is not that there is a fact and it is just unknown or ineffable to him, but whether there is a fact of the matter about something is completely relative to the observer.
- c.f. many-worlds, in which there is no fact of the matter for Wigner because both Friends exist.
- Quantum theory describes individual perspectival realities, which, happily, under normal circumstances we are able to achieve intersubjective agreement about.
- However, reality "for me" is fundamentally different from reality "for you". There is no global, agent independent reality, even one just composed of detector clicks.
- QBism is an example of this type of view.

10 Dirty Secrets

1. The problem of quantum jumps.
2. There is no Copenhagen interpretation.
3. Viable Copenhagen interpretations must be perspectival.
4. We don't agree on what the problem is.
5. The Heisenberg and Schrödiner "pictures" are not equivalent.
6. We don't agree on what "realism" means.
7. We don't agree what the assumptions of Bell's theorem are.
8. The Schrödinger's cat paradox is not the same as the measurement problem.
9. All realist theories are fine-tuned.
10. The words "classical" and "quantum" are meaningless.