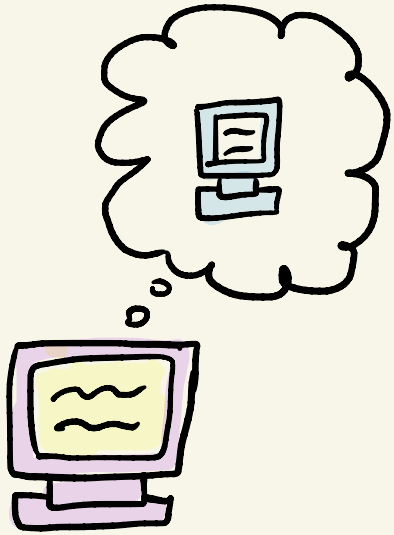
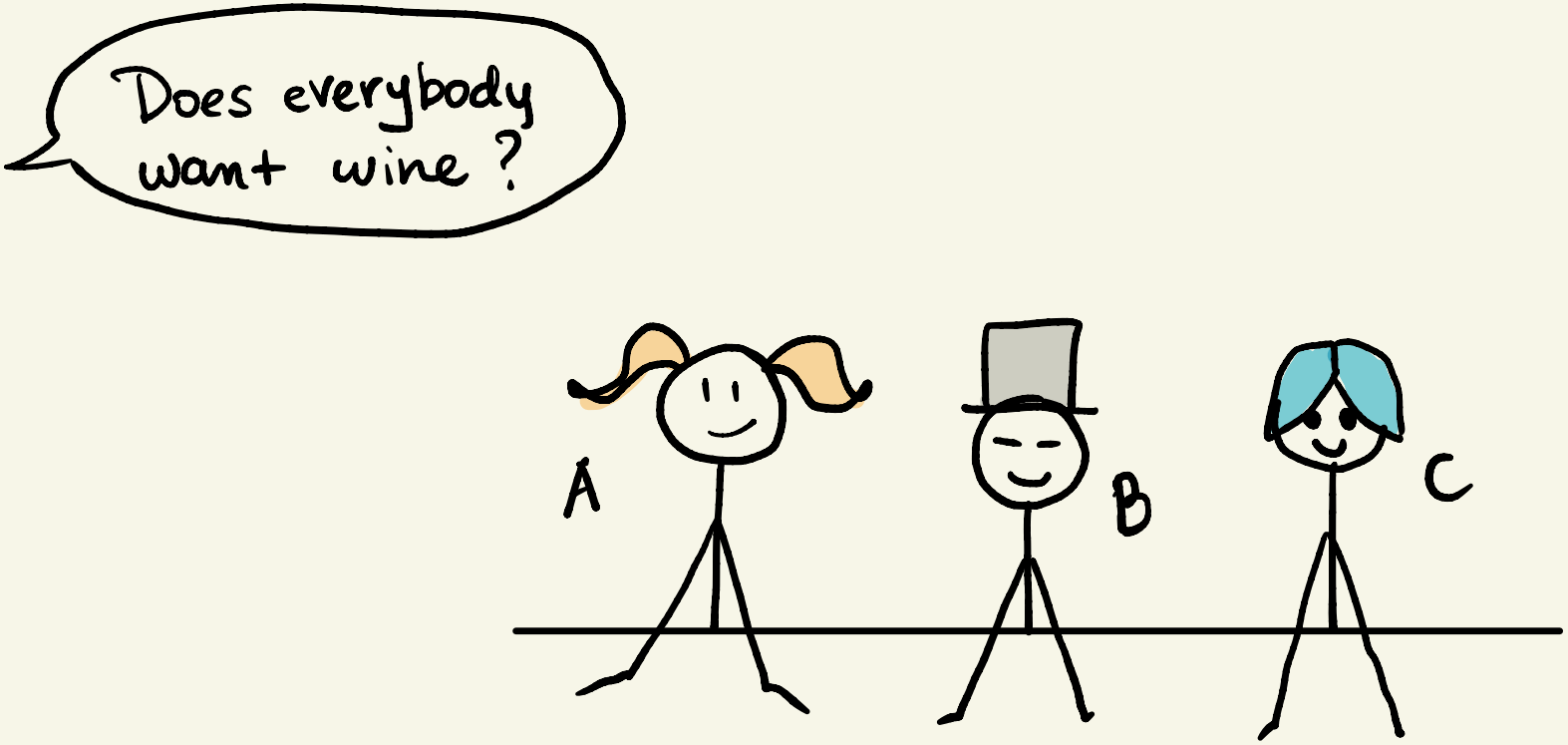
Testing quantum theory with thought experiments



BNL quantum journal club,
December 2021

based on joint work by Simon Mathis, Nuriya Nurgalieva,
Lídia del Rio and Renato Renner

Motivation



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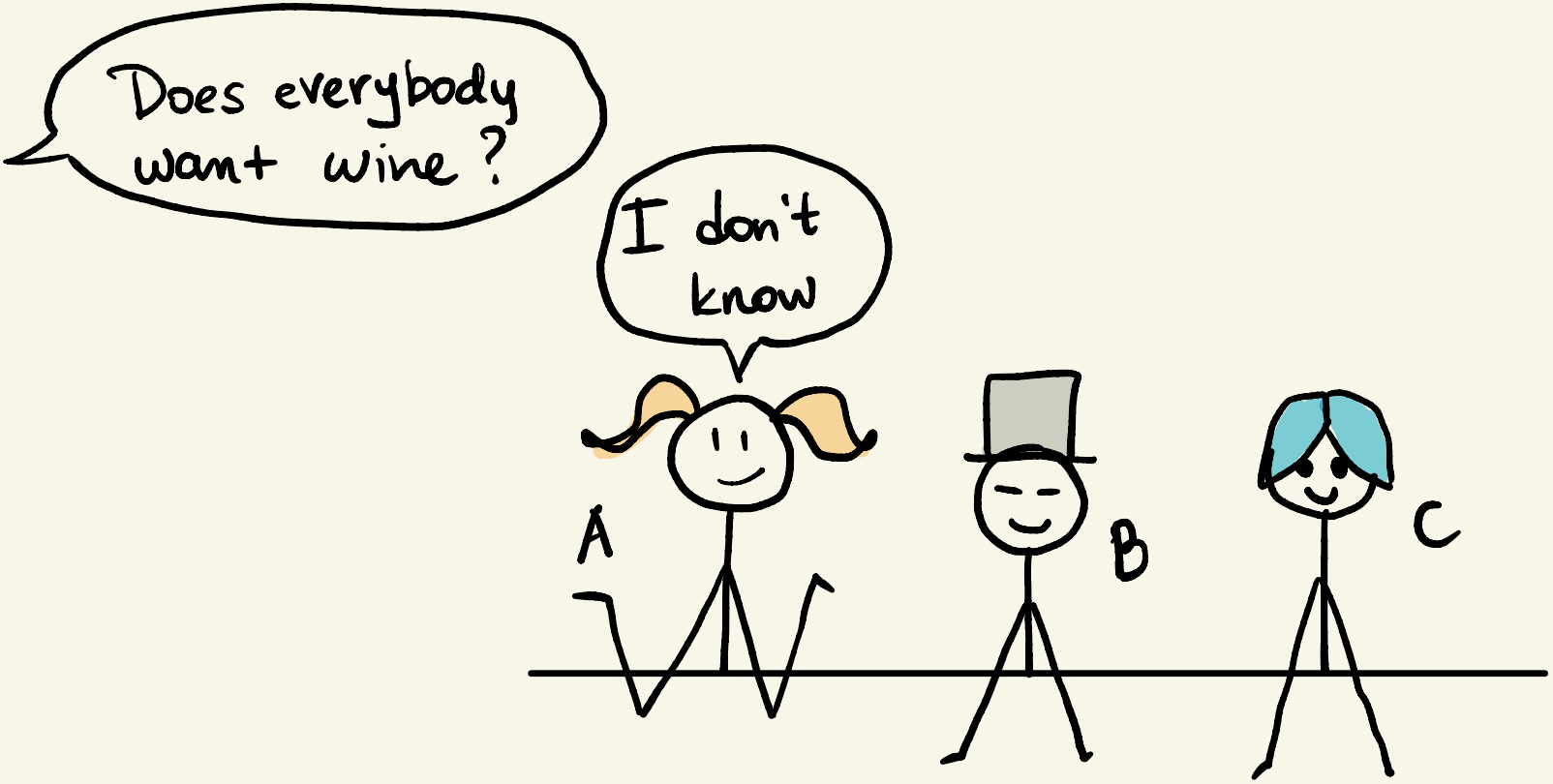

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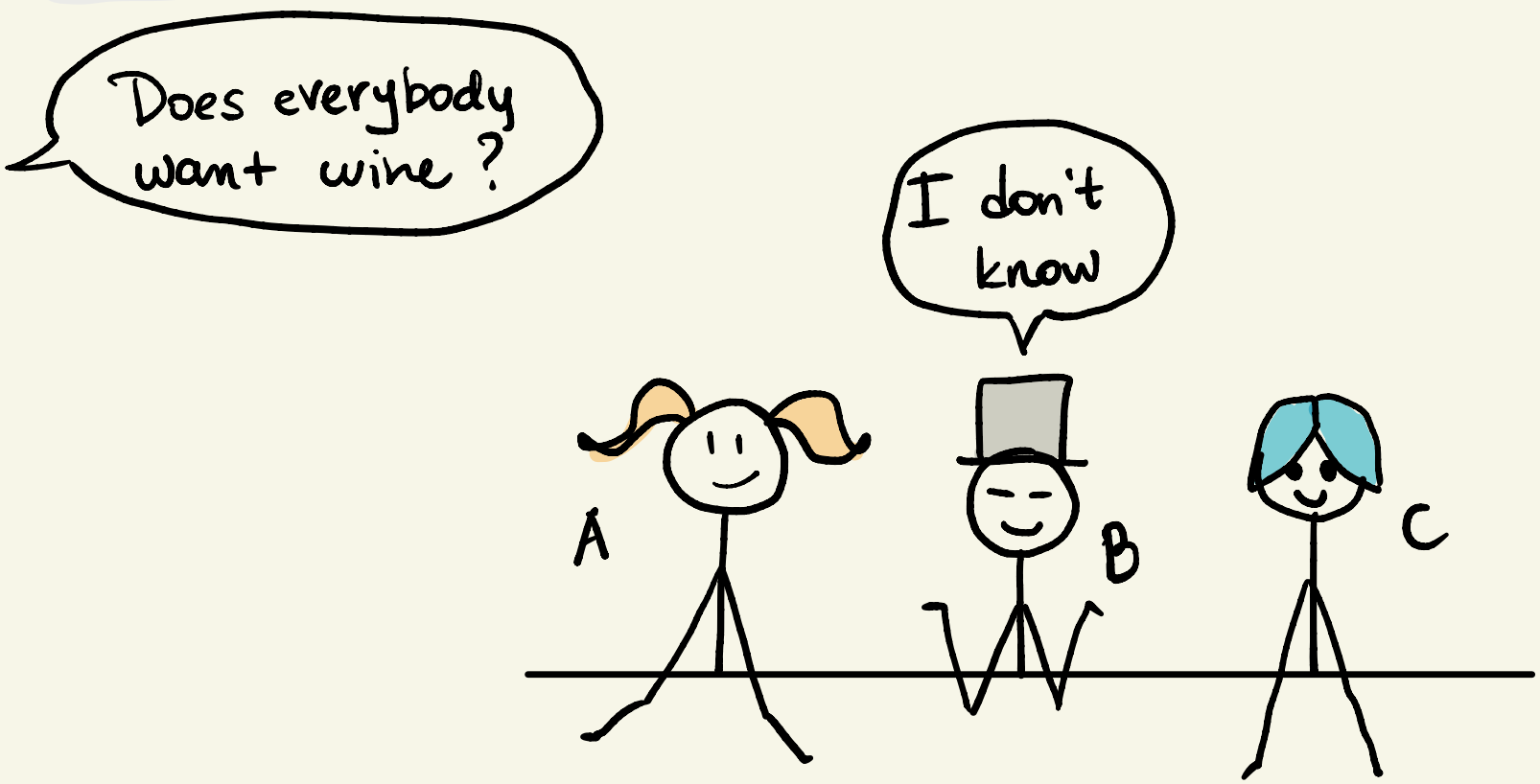
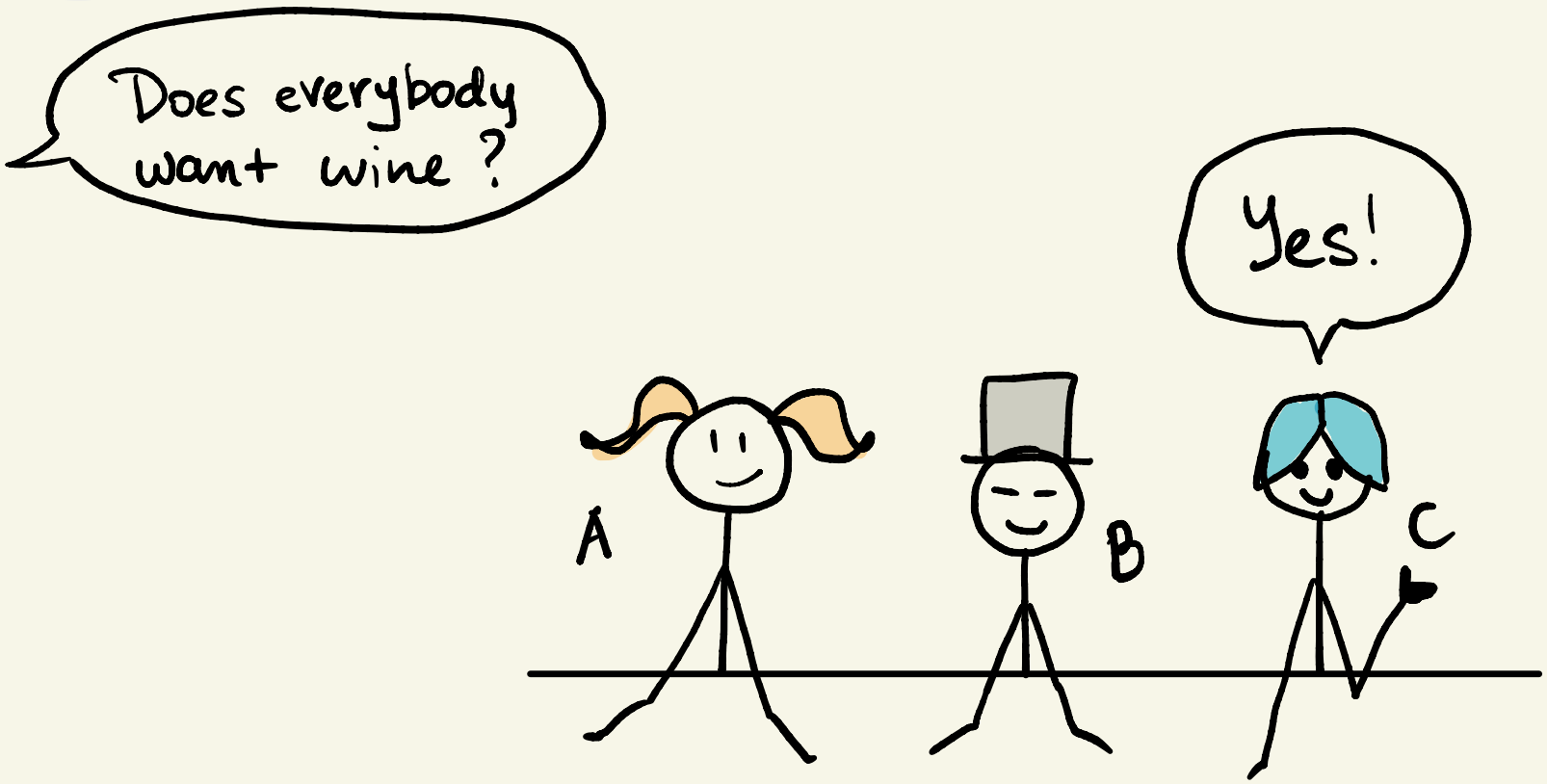
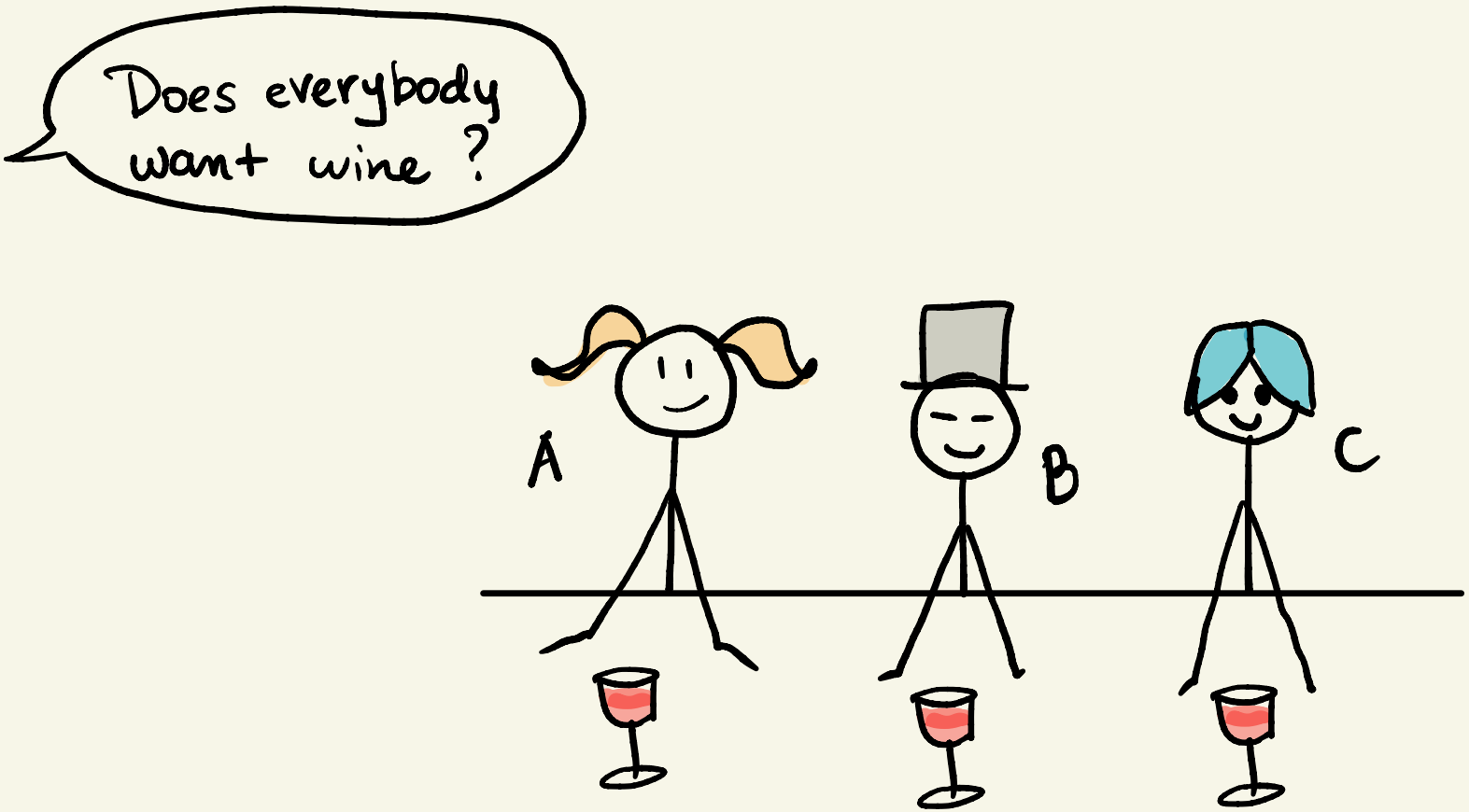


Motivation



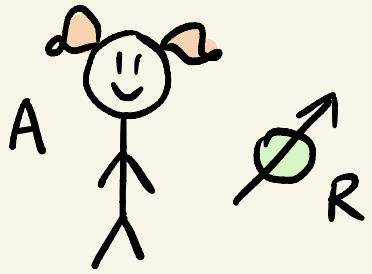
Motivation



Contents

* reasoning agents : example
* modeling measurements
* modeling reasoning
* testing example : FR
* assumptions & interpretations
* software package

Reasoning agents : example



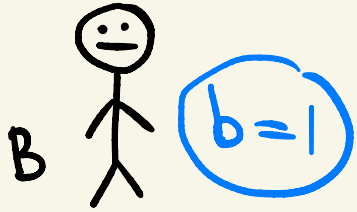
$$\frac{1}{\sqrt{3}}|0\rangle_R + \sqrt{\frac{2}{3}}|1\rangle_R$$

if $a=0$

if $a=1$

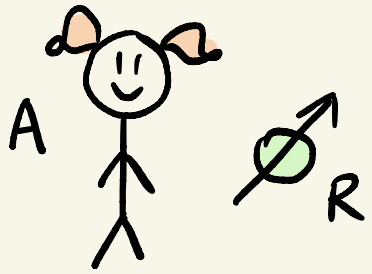
$|0\rangle_S$

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



if $b=1$ what did Alice measure?

Reasoning agents : example



$$\frac{1}{\sqrt{3}}|0\rangle_R + \sqrt{\frac{2}{3}}|1\rangle_R$$

if $a=0$

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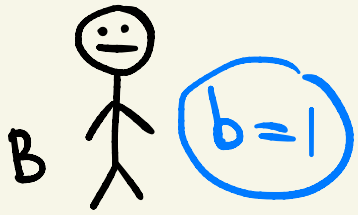
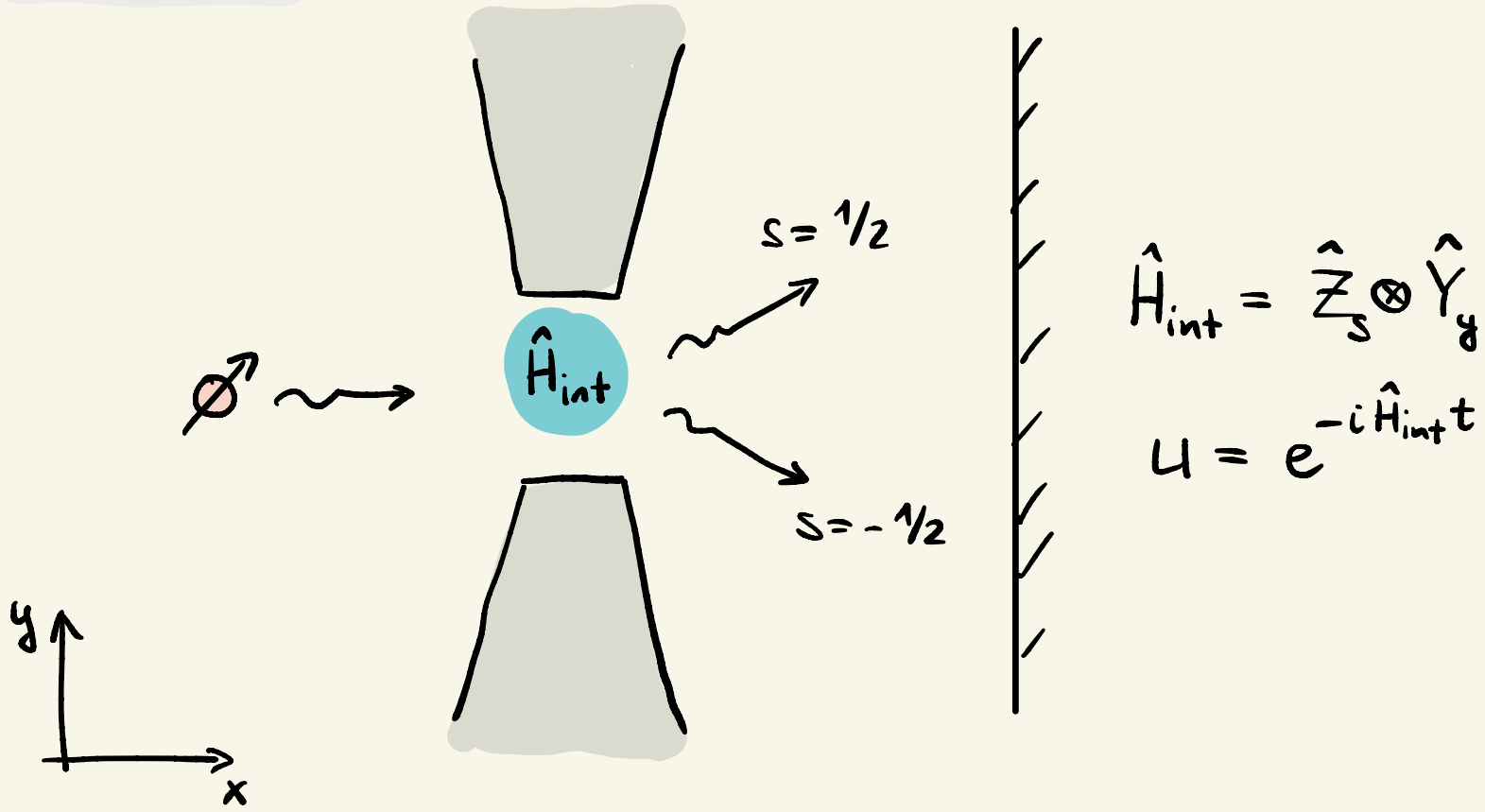
$\frac{1}{\sqrt{2}}|0\rangle_S + \frac{1}{\sqrt{2}}|1\rangle_S$



if $b=1$ what did Alice measure? $a=1$

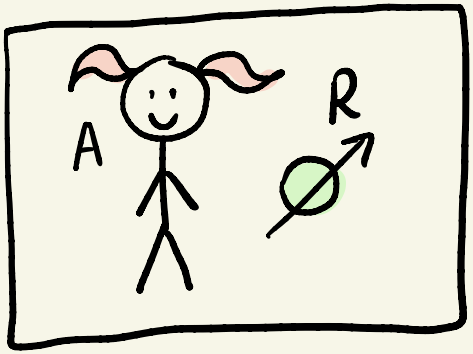
Example: Stern-Gerlach experiment

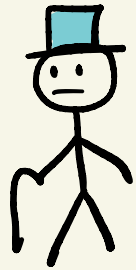


$$\hat{H}_{int} = \hat{Z}_s \otimes \hat{Y}_y$$

$$U = e^{-i\hat{H}_{int}t}$$

Example : CNOT as memory update



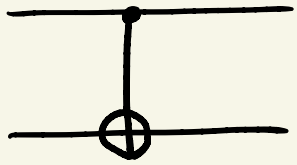


(Wigner's friend)

Alice : R $\alpha|0\rangle_R + \beta|1\rangle_R$

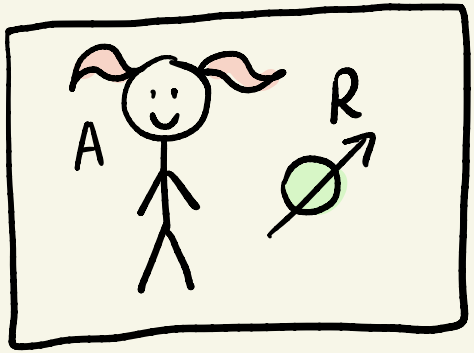
Wigner: R $\alpha|0\rangle_R + \beta|1\rangle_R$

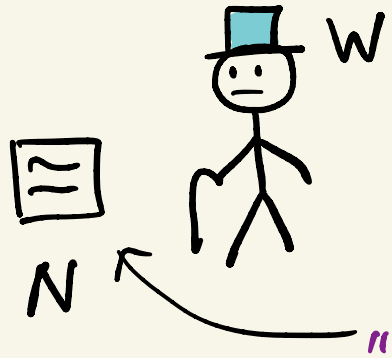
A $|0\rangle_A$



$\alpha|00\rangle_{RA} + \beta|11\rangle_{RA}$

Example: Deutsch's version of Wigner's friend



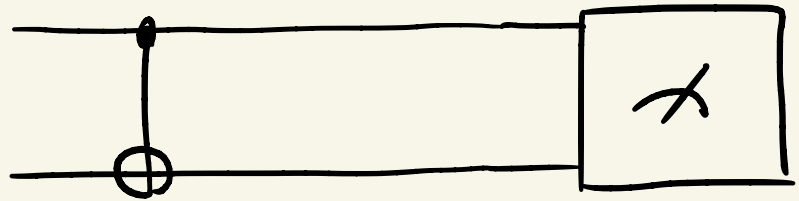


"definite outcome"

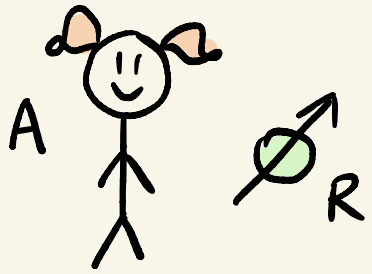
R $\alpha|0\rangle_R + \beta|1\rangle_R$

A $|0\rangle_A$

N $|0\rangle_N$



Reasoning agents : example



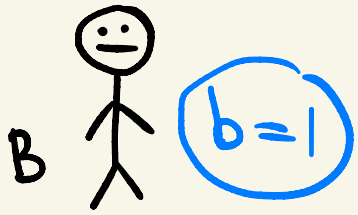
$$\frac{1}{\sqrt{3}}|0\rangle_R + \sqrt{\frac{2}{3}}|1\rangle_R$$

if $a=0$

if $a=1$

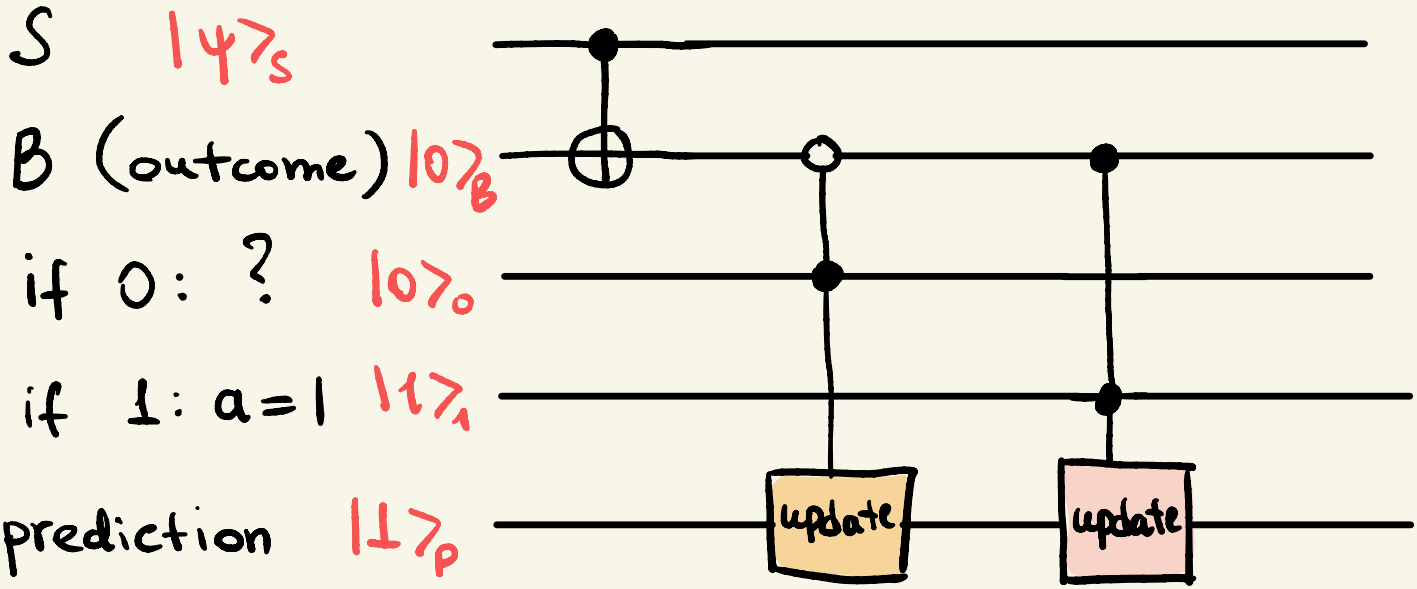
$|0\rangle_S$

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

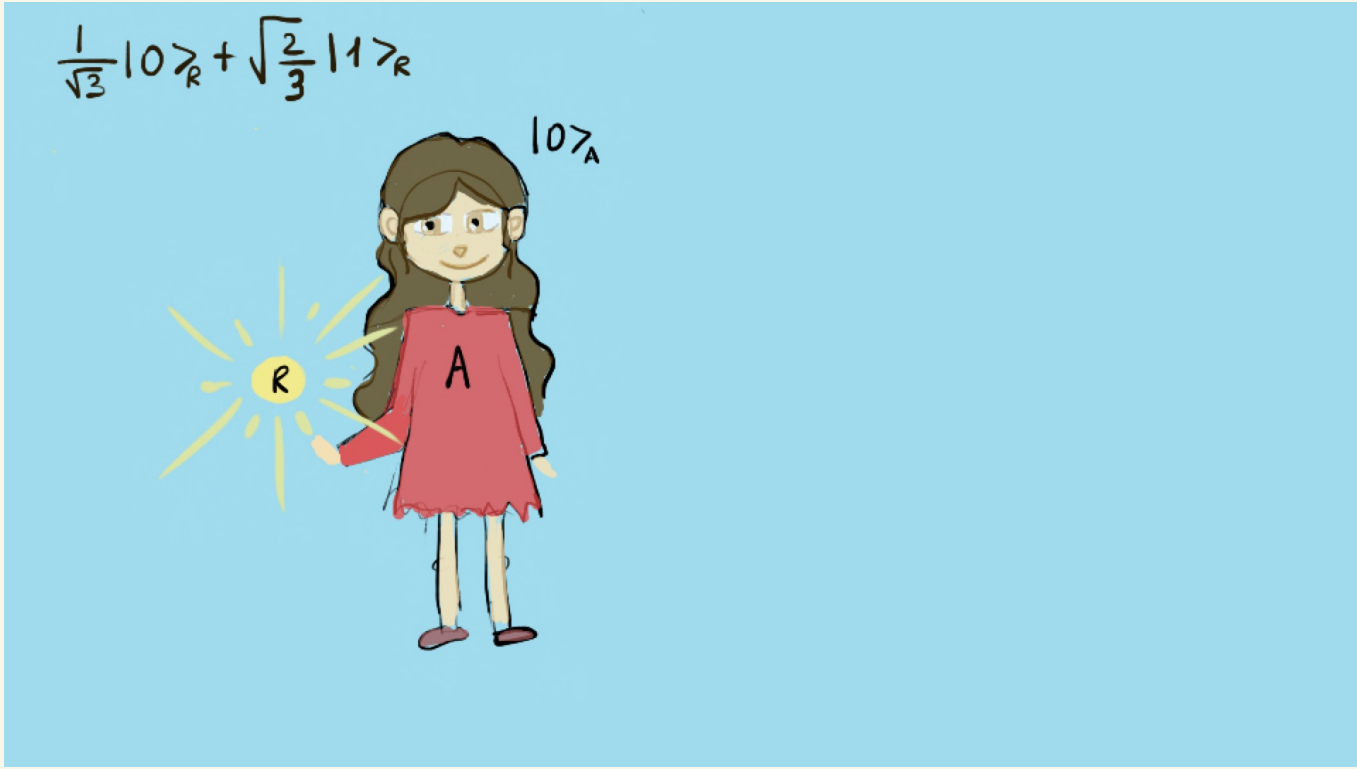


if $b=1$ what did Alice measure? $a=1$

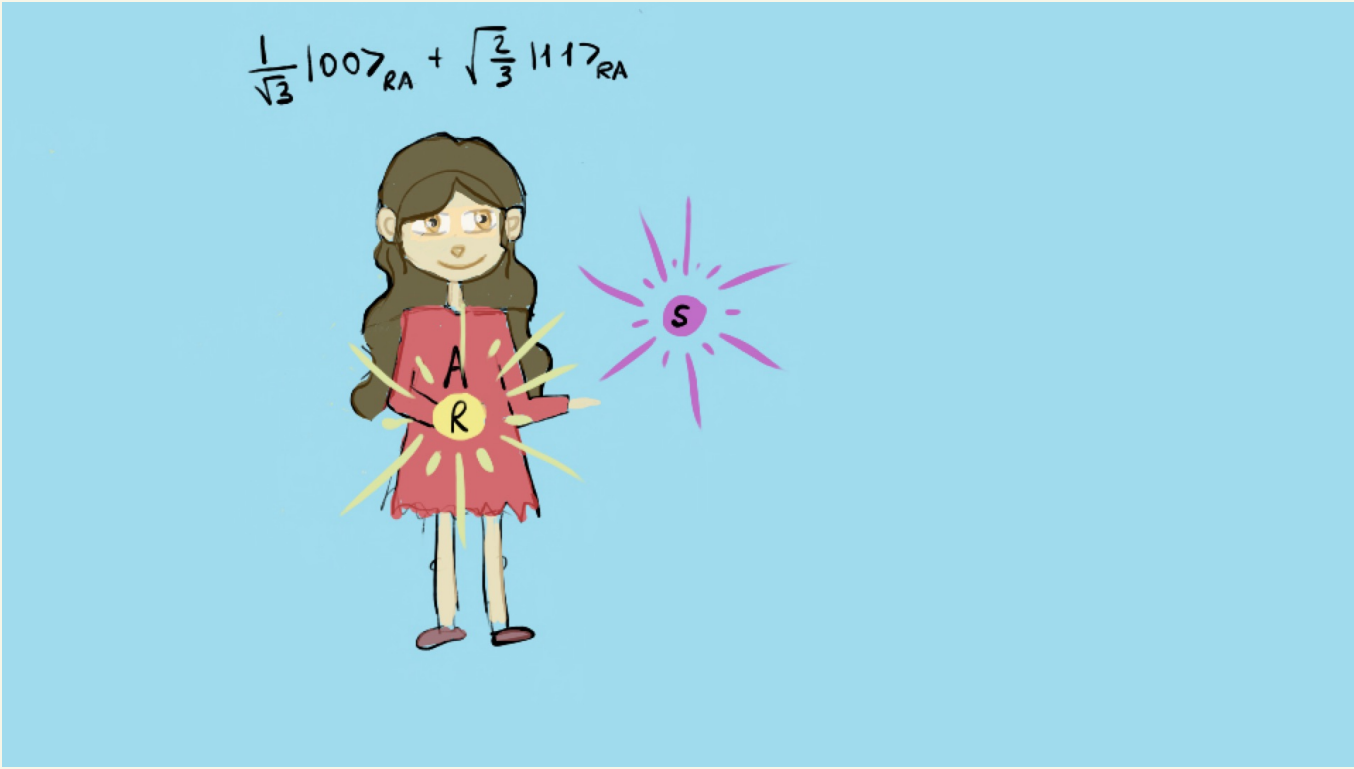
Example : reasoning as a circuit



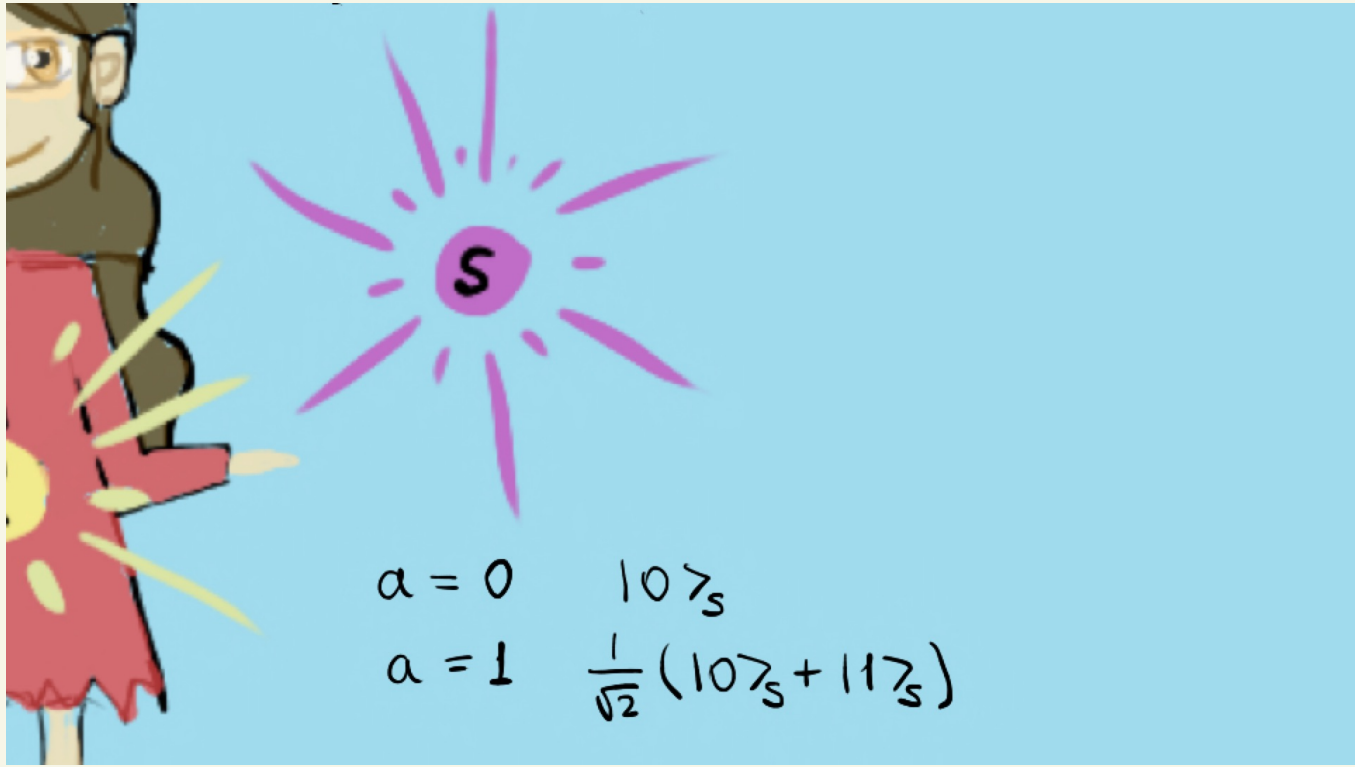
Testing example : FR thought experiment



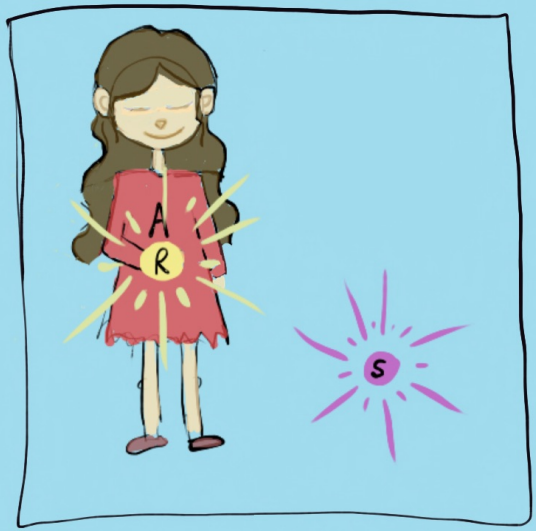
Testing example : FR thought experiment



Testing example : FR thought experiment

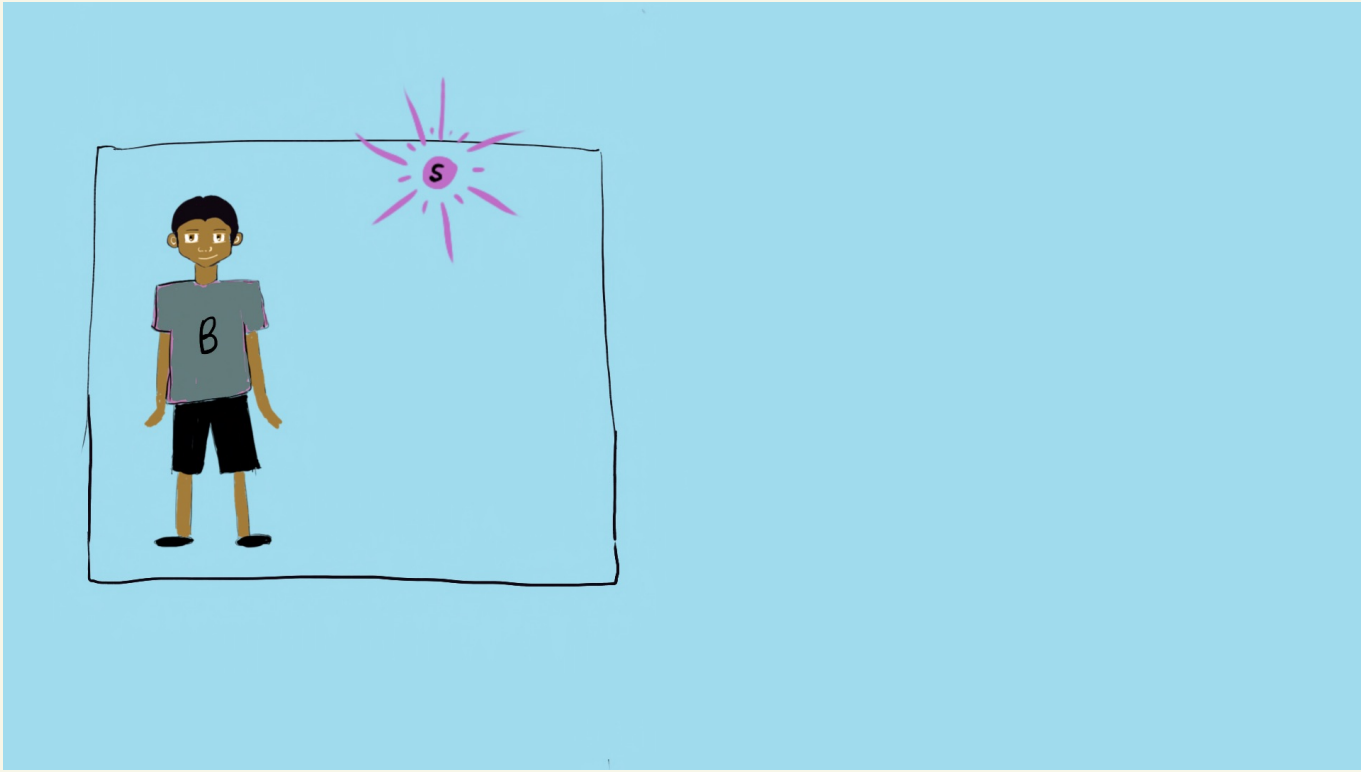


Testing example : FR thought experiment

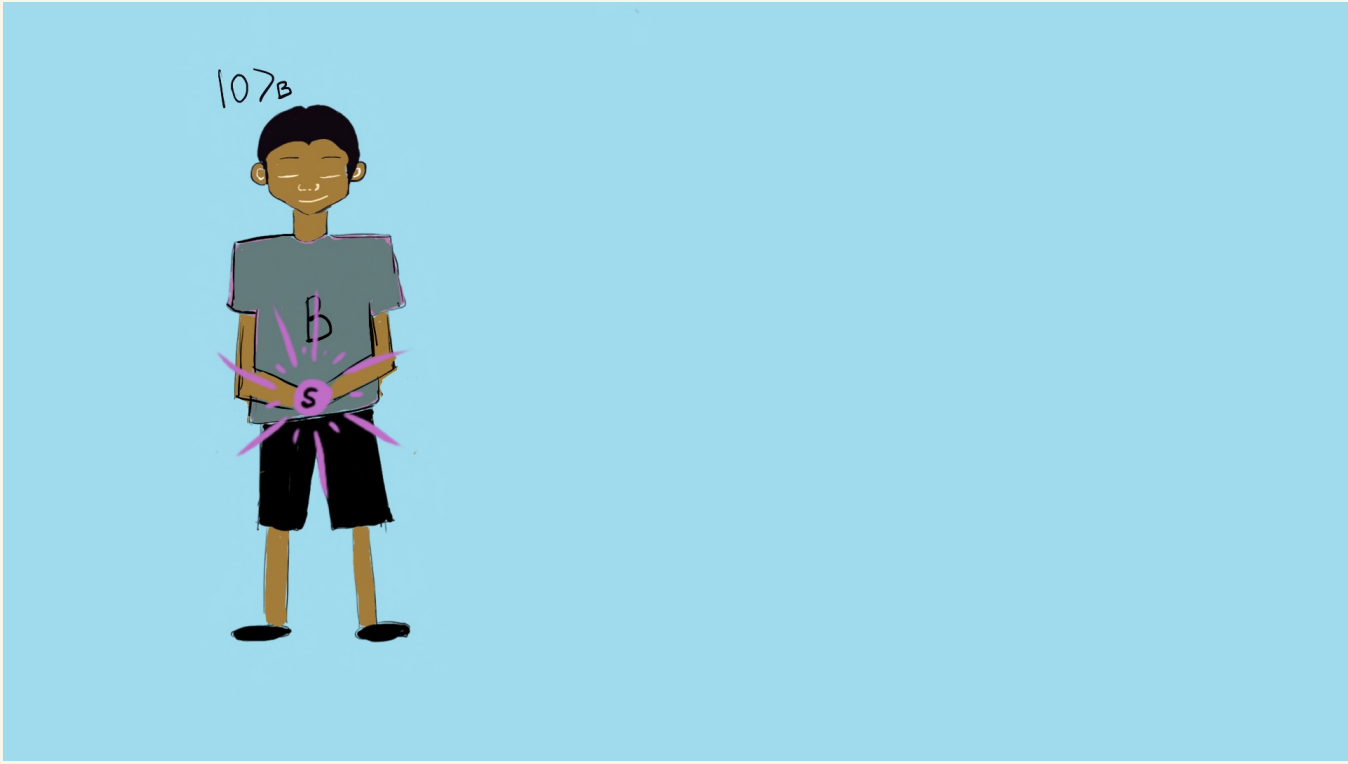


$$\frac{1}{\sqrt{3}}|00\rangle_{RA}|0\rangle_S + \frac{1}{\sqrt{3}}|11\rangle_{RA}|0\rangle_S + \frac{1}{\sqrt{3}}|11\rangle_{RA}|1\rangle_S$$

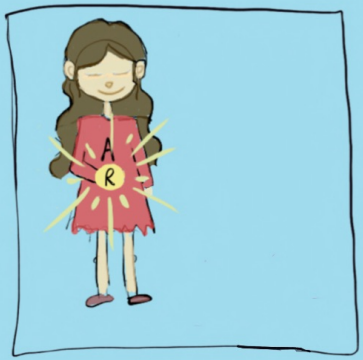
Testing example : FR thought experiment

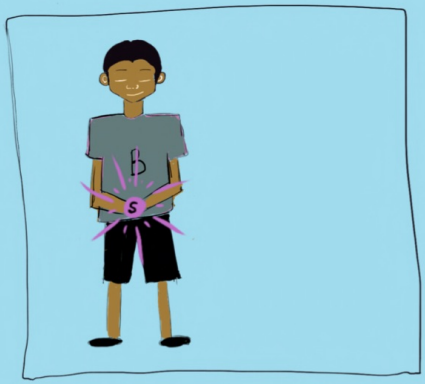


Testing example : FR thought experiment



Testing example : FR thought experiment

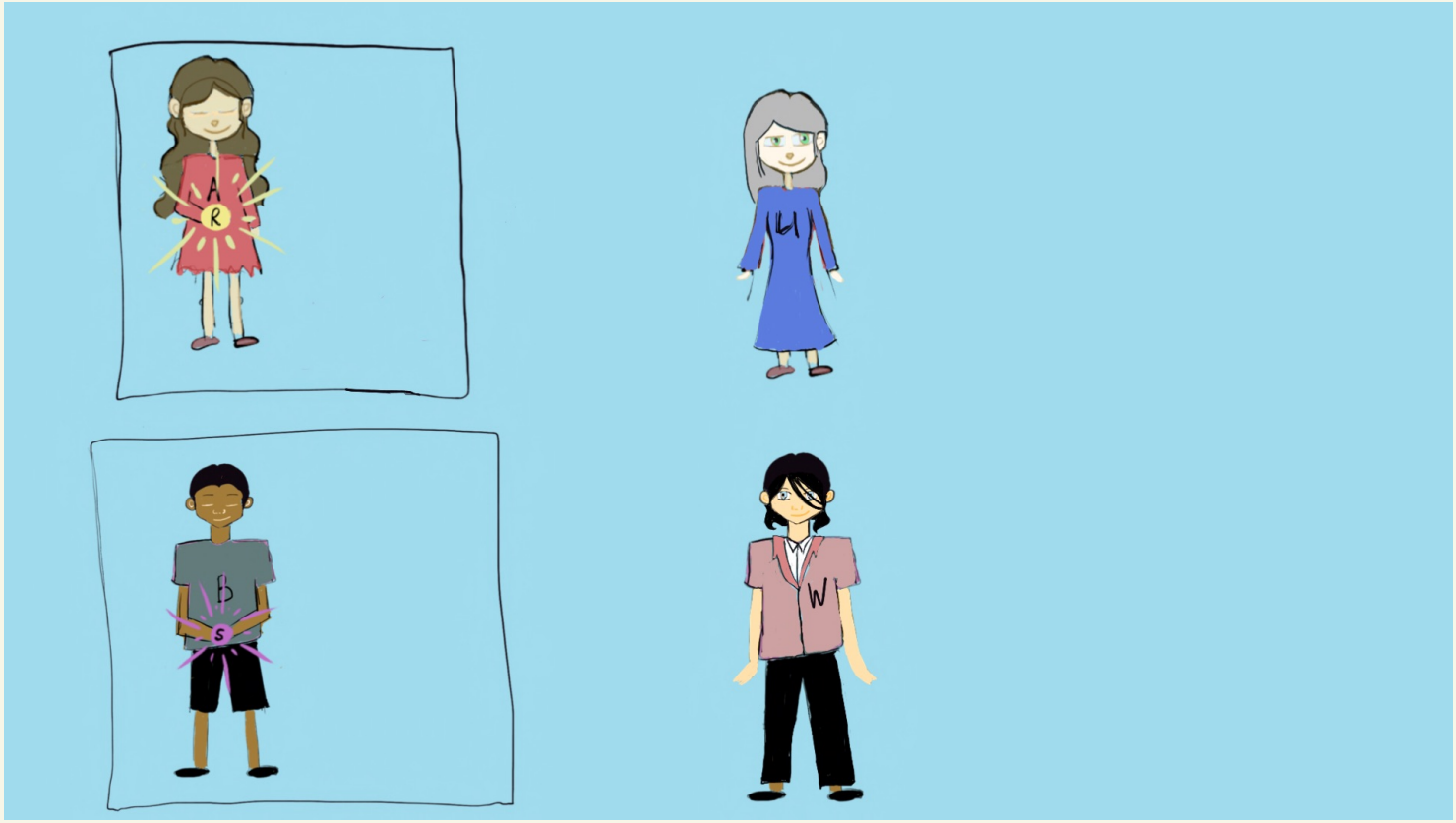




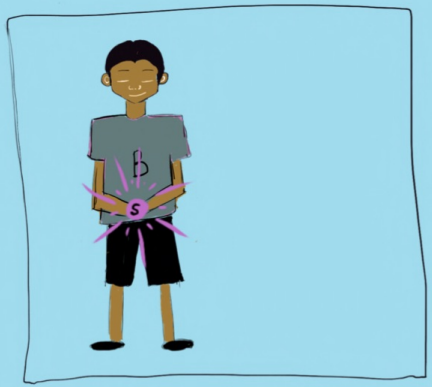
$$\frac{1}{\sqrt{3}}|00\rangle_{RA}|00\rangle_{SB} + \frac{1}{\sqrt{3}}|11\rangle_{RA}|00\rangle_{SB} +$$

$$+ \frac{1}{\sqrt{3}}|11\rangle_{RA}|11\rangle_{SB}$$

Testing example : FR thought experiment



Testing example : FR thought experiment



$$|ok\rangle_{RA} = \frac{|00\rangle_{RA} - |11\rangle_{RA}}{\sqrt{2}}$$

$$|fail\rangle_{RA} = \frac{|00\rangle_{RA} + |11\rangle_{RA}}{\sqrt{2}}$$

$$|ok\rangle_{SB} = \frac{|00\rangle_{SB} - |11\rangle_{SB}}{\sqrt{2}}$$

$$|fail\rangle_{SB} = \frac{|00\rangle_{SB} + |11\rangle_{SB}}{\sqrt{2}}$$

Testing example : FR thought experiment

$$\frac{1}{\sqrt{3}}|00\rangle_{RA}|00\rangle_{SB} + \frac{1}{\sqrt{3}}|11\rangle_{RA}|00\rangle_{SB} + \frac{1}{\sqrt{3}}|11\rangle_{RA}|11\rangle_{SB}$$

$$\frac{1}{\sqrt{3}}\underbrace{(|00\rangle_{RA} + |11\rangle_{RA})}_{|fail\rangle_{RA}}|00\rangle_{SB} + \frac{1}{\sqrt{3}}|11\rangle_{RA}|11\rangle_{SB}$$

(Ursula)

$u = ok \Rightarrow b = 1$

Testing example : FR thought experiment

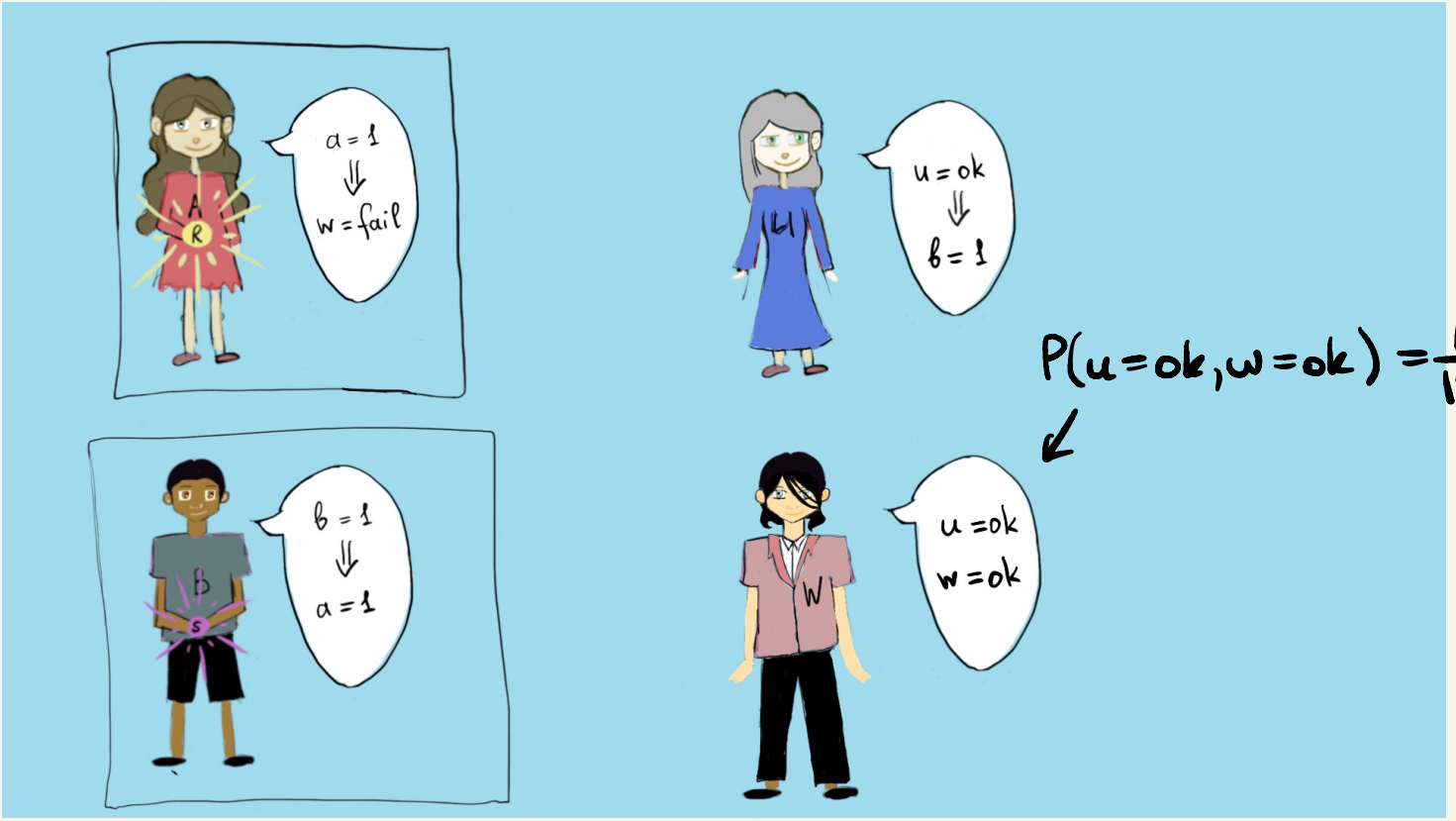
$$\frac{1}{\sqrt{3}}|00\rangle_{RA}|00\rangle_{SB} + \frac{1}{\sqrt{3}}|11\rangle_{RA}|00\rangle_{SB} + \frac{1}{\sqrt{3}}|11\rangle_{RA}|11\rangle_{SB}$$

$$\frac{1}{\sqrt{3}}|00\rangle_{RA}|00\rangle_{SB} + \frac{1}{\sqrt{3}}|11\rangle_{RA}\underbrace{(|00\rangle_{SB} + |11\rangle_{SB})}_{|fail\rangle_{SB}}$$

(Wigner)

$a=1 \Rightarrow w = fail$

Testing example : FR thought experiment



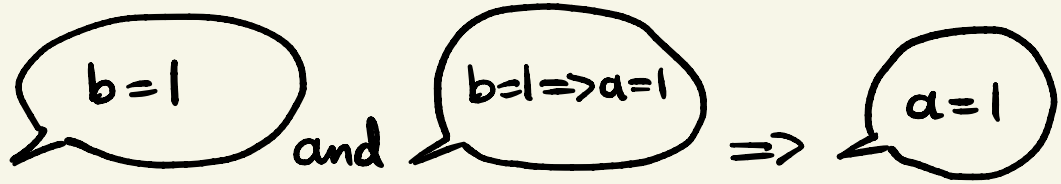
$$P(u=ok, w=ok) = \frac{1}{12} > 0$$

Testing example : FR thought experiment

Testing example : FR thought experiment

Assumptions

Logic

Consistency : 

Single outcome : 

Interpretation

Quantum theory : deterministic Born rule

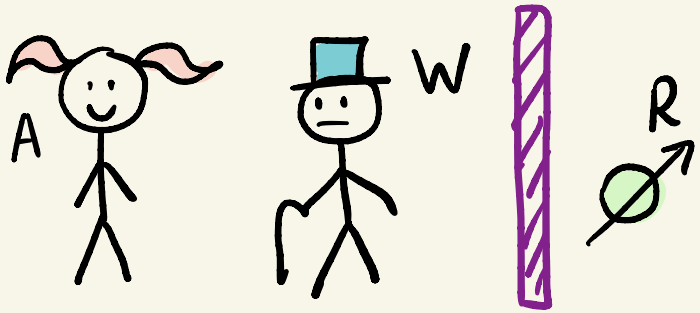
(Unitarity : modeling evolution as unitary)

Interpretations

Range of applicability + role of agents

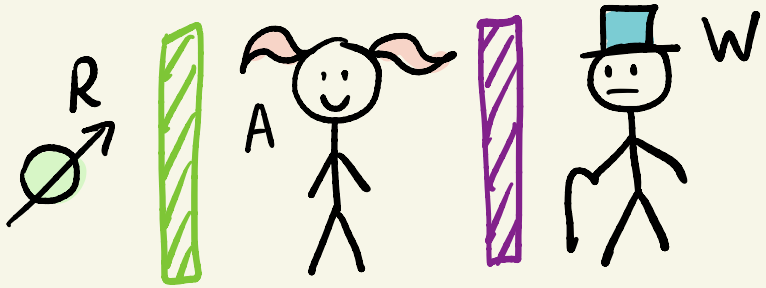
Observer required		
Interpretation	*Features*	*Range of applicability of QT*
Conventional Copenhagen	objective cut between the observer and the observed	any system under the cut
Neo-Copenhagen	subjective cut between the observer and the observed	any system under the cut
QBism	theory applied from perspective of observer	any system excluding the observer
Many-worlds	measurements by observer induce branching into worlds	entire universe
No observer required		
Interpretation	*Features*	*Range of applicability of QT*
Bohmian mechanics	complements quantum theory with hidden variables	entire universe
Relational quantum mechanics	description always relative to another system	any system in relation to another
ETH approach	considers restricted set of observables	dependent on set of observables
Consistent histories	considers restricted set of possible events	dependent on set of events
Objective collapse theories (GRW)	modification of Schrödinger equation yields non-unitarity	microscopic systems
Montevideo interpretation	gravitation induces non-unitarity	microscopic systems

Interpretations



Copenhagen:

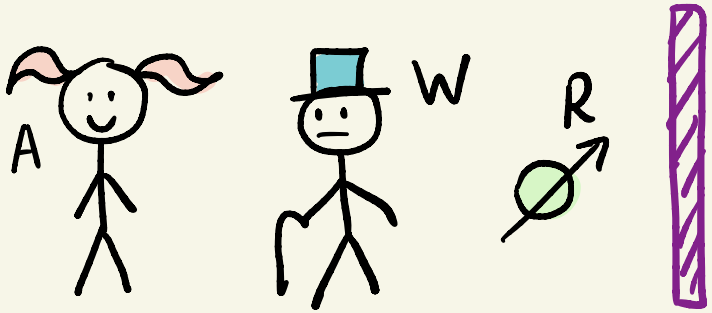
cut the same for all observers



Neo-Copenhagen:

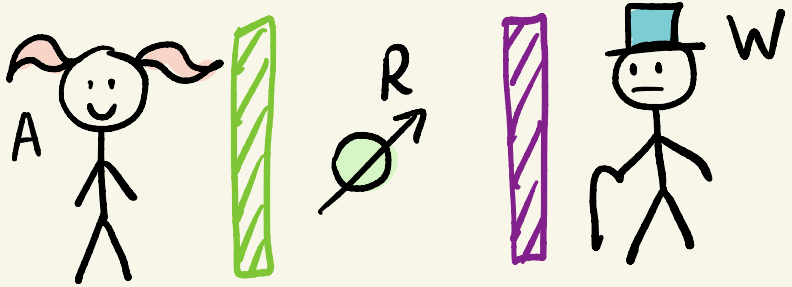
subjective cut

Interpretations



Many-worlds:

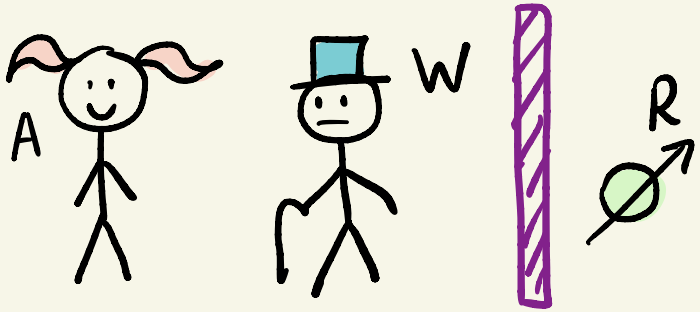
the entire universe is below the cut



QBism:

any observer is above their own cut

Interpretations



Collapse theories:

the cut is fundamentally fixed

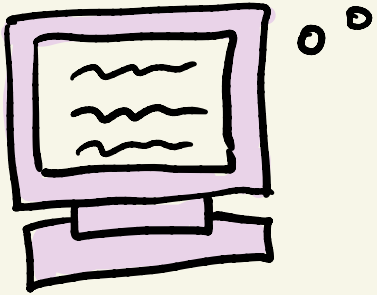
(only microscopic systems under)

Software package

Logic

Agent

Interpretation



Protocol

1. . . . .
2. . . .
3. . . . .

conclusion!

Come and test:

your favorite axiom system

Logic

- modal logic
- paraconsistent
- ...

your model for

Agent

your preferred

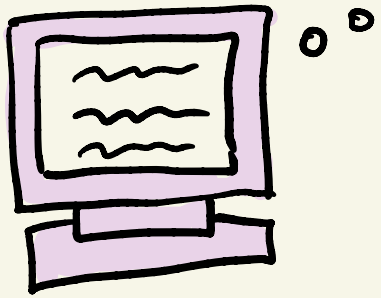
Interpretation

- (neo) Copenhagen
- collapse theories
- ...

desired communication

Protocol

1. ....
2. ...
3. ....



conclusion!

[consistent or inconsistent]

Github repo →

Thought exp. & interpret. →

Thank you for your attention!