Wigner and his “friends”

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and

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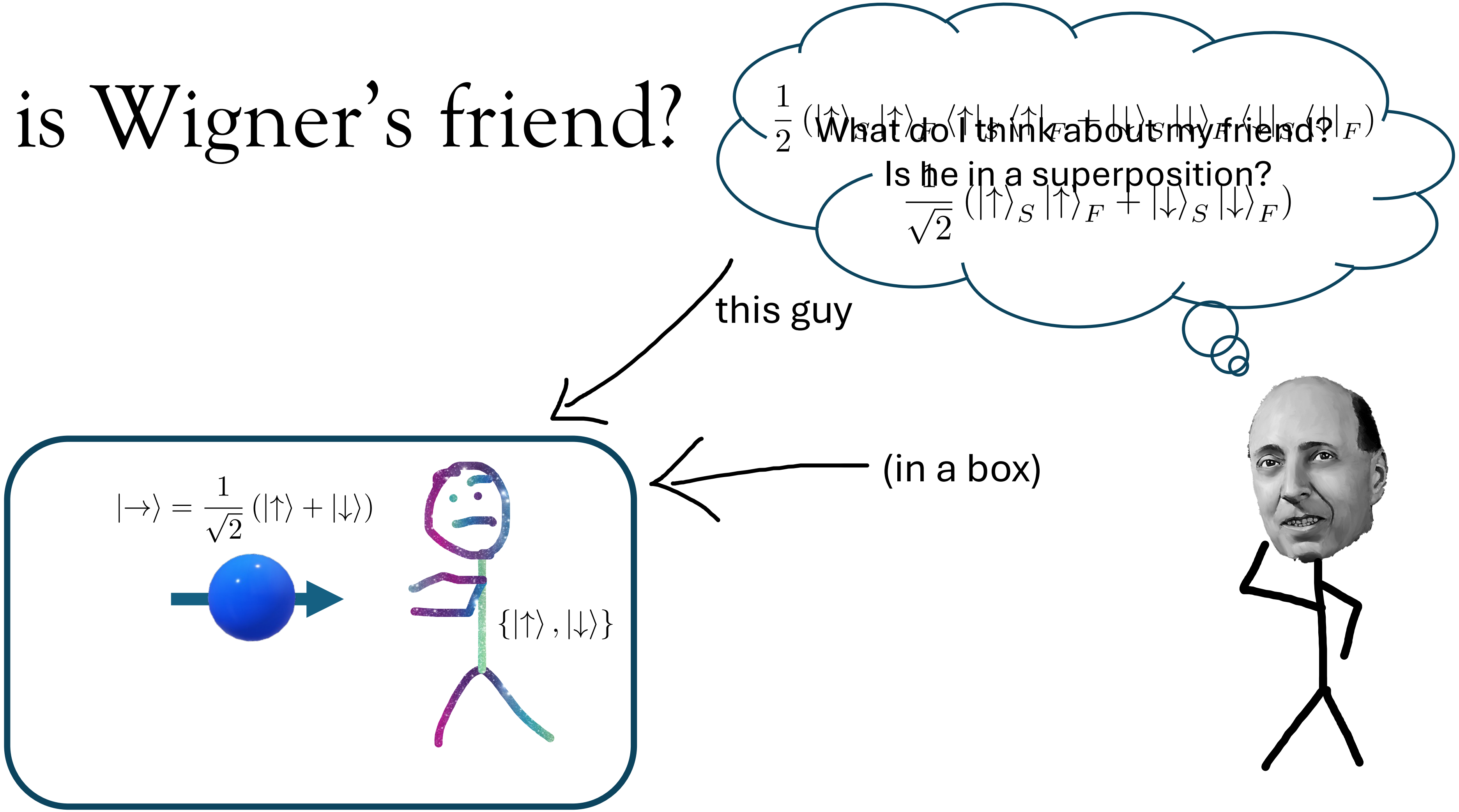
Who is Wigner's friend?

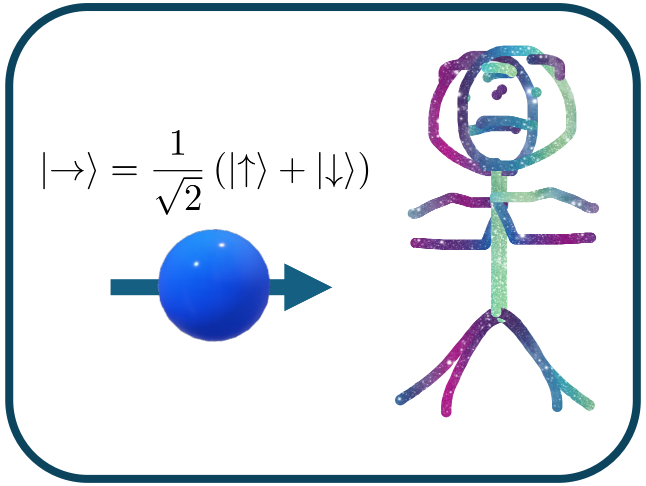


Is there actually a contradiction?
Is there a paradox?

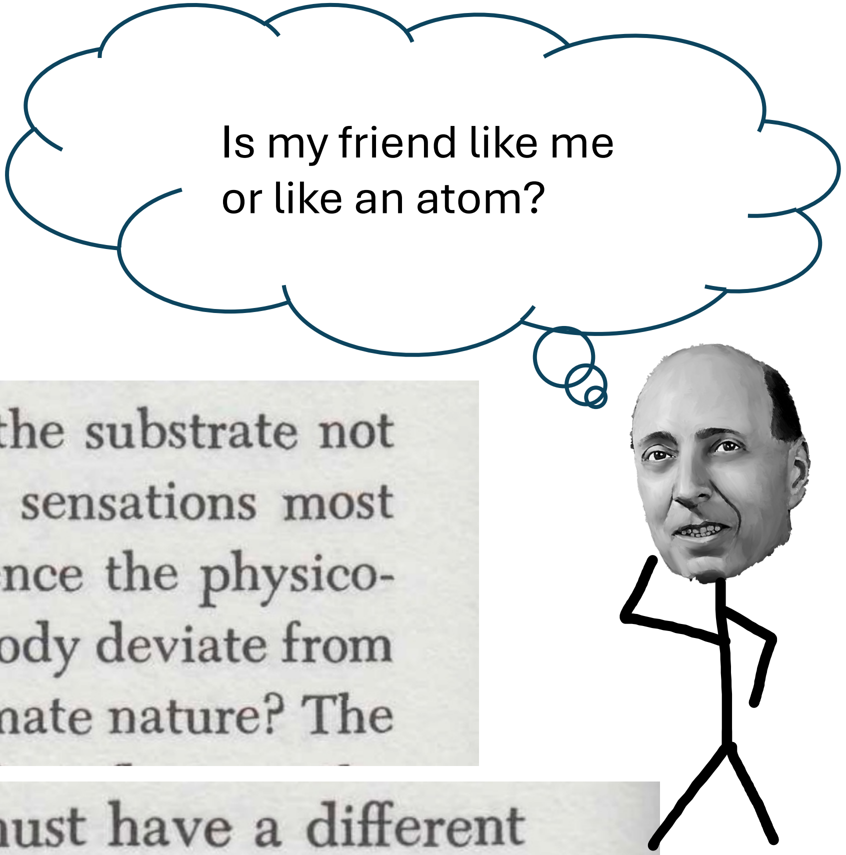
- No contradiction: Both Wigner and Friend will agree *every single time* after they communicate and match their outcomes.

- Their state assignments are different, but both assignments predict correct probabilities of z basis measurements.

- Wigner talking to the friend and asking him the outcome is Wigner measuring the friend in z basis.



Who cares?



The physico-chemical conditions and properties of the substrate not only create the consciousness, they also influence its sensations most profoundly. Does, conversely, the consciousness influence the physico-chemical conditions? In other words, does the human body deviate from the laws of physics, as gleaned from the study of inanimate nature? The

It follows that the being with a consciousness must have a different role in quantum mechanics than the inanimate measuring device: the atom considered above. In particular, the quantum mechanical equations of motion cannot be linear if the preceding argument is accepted.

Wigner, Eugene P. "Remarks on the mind-body question." *Philosophical reflections and syntheses*. Berlin, Heidelberg: Springer Berlin Heidelberg, 1995. 247-260.

Extended Wigner's Friend and Assumptions

1. Assumption (Q): Agents who use the Born rule to predict that a measurement outcome ξ will happen with probability 1 can be certain of that outcome.

2. Assumption (C): If agent A is certain of a measurement outcome ξ, and agent B *knows* that agent A is certain of ξ, then agent B must also be certain of ξ.

3. Assumption (S): If agent A is certain of measurement outcome ξ, then they must also be certain that any other measurement outcome has probability 0.

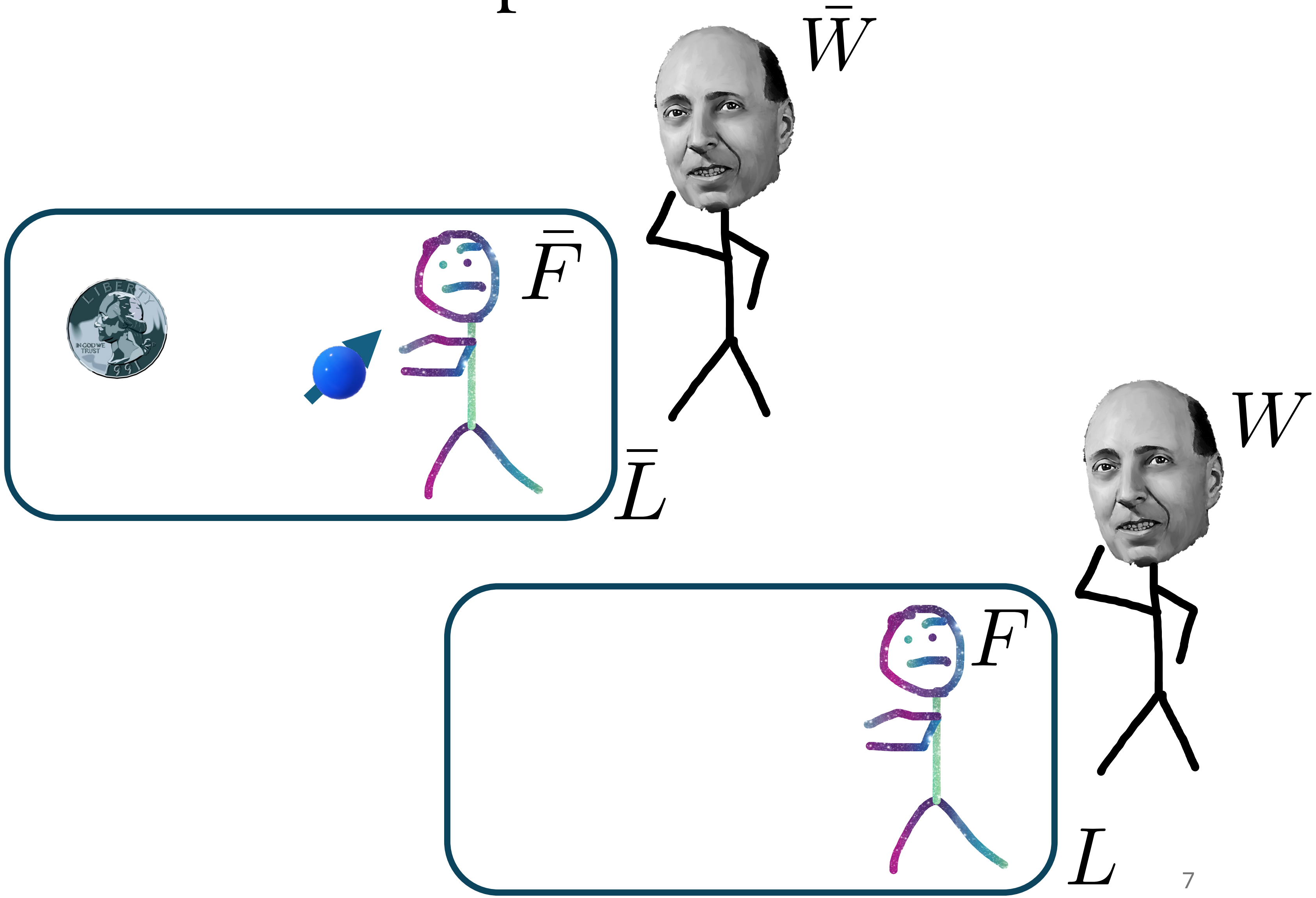
Implications of this result

	(Q)	(C)	(S)
Copenhagen interpretation	✓	×	✓
HV theory applied to subsystems	✓	×	✓
HV theory applied to entire universe	×	✓	✓
Many-worlds interpretations	?	?	×
Collapse theories	×	✓	✓
Consistent histories	✓	×	✓
QBism	✓	×	✓
Relational quantum mechanics	✓	×	✓
CSM approach	×	✓	✓
ETH approach	×	✓	✓

Frauchiger, Daniela, and Renato Renner. "Quantum theory cannot consistently describe the use of itself." *Nature communications* 9.1 (2018): 3711.

Extended Wigner's friend setup

- All agents begin the experiment by agreeing on a protocol.
- All the friends can do is measure within their box and reason about other agents.
- All the Wigners can do is measure their respective friends' lab, and shout at each other (they share a classical communication channel).



Notation and measurements

Can measure the coin in the following basis

$$|+\rangle_C = \frac{1}{\sqrt{2}}\left(|H\rangle + |T\rangle\right)$$

$$|-\rangle_C = \frac{1}{\sqrt{2}}\left(|H\rangle - |T\rangle\right)$$

$\bar{W}$

All "bars"

Can flip a coin

$\bar{F}$

$\bar{L}$

W

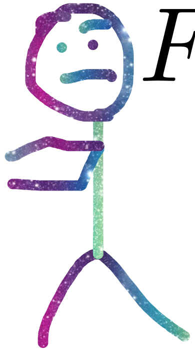
Can measure the lab in the following basis

$$|+\rangle_L = \frac{1}{\sqrt{2}}\left(|\uparrow\rangle_S |\uparrow\rangle_F + |\downarrow\rangle_S |\downarrow\rangle_F\right)$$

$$|-\rangle_L = \frac{1}{\sqrt{2}}\left(|\uparrow\rangle_S |\uparrow\rangle_F - |\downarrow\rangle_S |\downarrow\rangle_F\right)$$

All "not bars"

Can measure a qubit in the z basis



F

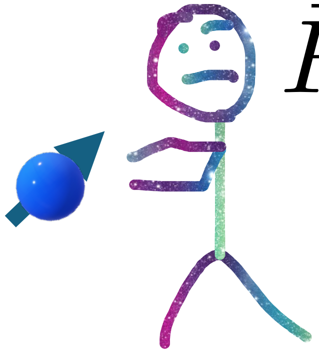
L

STEP 1

$\bar{L}$

H $^{1/3}$: $|\downarrow\rangle_S$

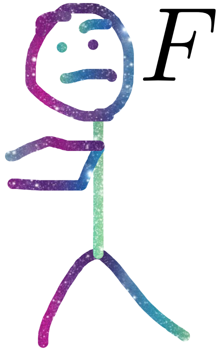
T $^{2/3}$: $\frac{1}{\sqrt{2}}(|\uparrow\rangle_S + |\downarrow\rangle_S)$



$\bar{F}$

STEP 2

L



F

STEP 3

$\bar{W}$

$|+\rangle_C = \frac{1}{\sqrt{2}}(|H\rangle + |T\rangle) \rightarrow \overline{\text{fail}}$

$|-\rangle_C = \frac{1}{\sqrt{2}}(|H\rangle - |T\rangle) \rightarrow \overline{\text{ok}}$

STEP 4

W

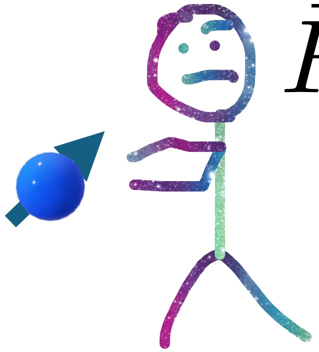
$|+\rangle_L = \frac{1}{\sqrt{2}}(|\uparrow\rangle_S |\uparrow\rangle_F + |\downarrow\rangle_S |\downarrow\rangle_F) \rightarrow \text{fail}$

$|-\rangle_L = \frac{1}{\sqrt{2}}(|\uparrow\rangle_S |\uparrow\rangle_F - |\downarrow\rangle_S |\downarrow\rangle_F) \rightarrow \text{ok}$

STEP 1

H $^{1}/_{3}$: $|\!\downarrow\rangle_S$

T $^{2}/_{3}$: $\frac{1}{\sqrt{2}}(|\!\uparrow\rangle_S + |\!\downarrow\rangle_S)$



$\bar{F}$

$\bar{L}$

$\bar{W}$

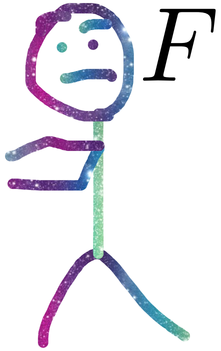
STEP 3

$$|+\rangle_C = \frac{1}{\sqrt{2}}(|H\rangle + |T\rangle) \rightarrow \overline{\text{fail}}$$

$$|-\rangle_C = \frac{1}{\sqrt{2}}(|H\rangle - |T\rangle) \rightarrow \overline{\text{ok}}$$

STEP 2

$|\!\uparrow\rangle_S$



F

L

W

STEP 4

fail

$$|+\rangle_L = \frac{1}{\sqrt{2}}(|\!\uparrow\rangle_S\,|\!\uparrow\rangle_F + |\!\downarrow\rangle_S\,|\!\downarrow\rangle_F)$$

$$|-\rangle_L = \frac{1}{\sqrt{2}}(|\!\uparrow\rangle_S\,|\!\uparrow\rangle_F - |\!\downarrow\rangle_S\,|\!\downarrow\rangle_F)$$

ok

What do we get if we apply our assumptions?

1. Assumption (Q): Agents can who use the Born rule to predict that a measurement outcome ξ will happen with probability 1 can be certain of that outcome.

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$$P(\mathrm{ok}, \overline{\mathrm{ok}}) = 0$$

but just using quantum mechanics, W can conclude that

$$P(\mathrm{ok}, \overline{\mathrm{ok}}) = \frac{1}{12}$$

What do we get if we apply our assumptions?

$$|+\rangle_C \to \overline{\text{fail}} \qquad |+\rangle_L \to \text{fail}$$
$$|-\rangle_C \to \overline{\text{ok}} \qquad |-\rangle_L \to \text{ok}$$

agent	assumed observation	statement inferred via (Q)	further implied statement	statement inferred via (C)
$\overline{F}$ (Ivy)	r = tails at time 1s	Statement $\overline{F}^{2s}$: "I am certain that W will observe w = fail at time 2s".		
F (Juan)	$z = +\frac{1}{2}$ at time 11s	Statement F^{12s} : "I am certain that $\overline{F}$ knows that r = tails at time 1s".	Statement F^{13s} : "I am certain that $\overline{F}$ is certain that W will observe w = fail at time 31s".	Statement F^{14s} : "I am certain that W will observe w = fail at time 31s".
$\overline{W}$ (Andrew)	$\overline{w} = \overline{ok}$ at time 21s	Statement $\overline{W}^{22s}$: "I am certain that F knows that $z = +\frac{1}{2}$ at time 11s".	Statement $\overline{W}^{23s}$: "I am certain that F is certain that W will observe w = fail at time 31s".	Statement $\overline{W}^{24s}$: "I am certain that W will observe w = fail at time 31s".
W (Mohsin)	announcement by agent $\overline{W}$ that $\overline{w} = \overline{ok}$ at time 21s	Statement W^{26s}: "I am certain that $\overline{W}$ knows that $\overline{w} = \overline{ok}$ at time 21s".	Statement W^{27s} : "I am certain that $\overline{W}$ is certain that I will observe w = fail at time 31s".	Statement W^{28s} : "I am certain that I will observe w = fail at time 31s".

What does Ivy think? ($\bar{F}$)

Fbar is going to make predictions about W's measurement on the lab L. Fbar knows that before W make's its measurement, the following two things happen:

1. F makes a measurement on the spin. Since Fbar doesn't know the outcome, but knows the state of the spin, it assumes that the friend F and spin are correlated in the following way (as a closed system should be):

$$|+\rangle_L = \frac{1}{\sqrt{2}}\left(|\uparrow\rangle_S |\uparrow\rangle_F + |\downarrow\rangle_S |\downarrow\rangle_F\right)$$

2. Wbar measures Lbar, this includes the friend Fbar. Since Fbar already sent away the spin to F. Fbar concludes that this should not affect the state above (circuit model).
3. Fbar concludes, from the state above, that W will fail. Since the state above is orthogonal to the okay outcome state: $|-\rangle_L = \frac{1}{\sqrt{2}}\left(|\uparrow\rangle_S |\uparrow\rangle_F - |\downarrow\rangle_S |\downarrow\rangle_F\right)$

What outcomes should we expect?

- We are interested in the probability of outcome when both Wigners measure “ok”.

$$
\begin{aligned}
&P(\bar{\mathrm{w}} = \bar{\mathrm{ok}}, \mathrm{w} = \mathrm{ok}) = \\
&= \left(\frac{1}{\sqrt{3}} \langle H|_C \otimes \langle \downarrow|_L + \sqrt{\frac{2}{3}} \langle T|_C \otimes \langle +|_L \right) \left(|-\rangle_C \langle -| \otimes |-\rangle_L \langle -| \right) \left(\frac{1}{\sqrt{3}} |H\rangle_C \otimes |\downarrow\rangle_L + \sqrt{\frac{2}{3}} |T\rangle_C \otimes |+\rangle_L \right) \\
&= \left(\frac{1}{\sqrt{3}} \langle H|_C \otimes \langle \downarrow|_L + \sqrt{\frac{2}{3}} \langle T|_C \otimes \langle +|_L \right) \left(-\frac{1}{2\sqrt{3}} |-\rangle_C \otimes |-\rangle_L \right) \\
&= \frac{1}{12}
\end{aligned}
$$

What outcomes should we expect?

$$P(\bar{\mathrm{w}} = \bar{\mathrm{ok}}, \mathrm{z} = -\frac{1}{2}) =$$

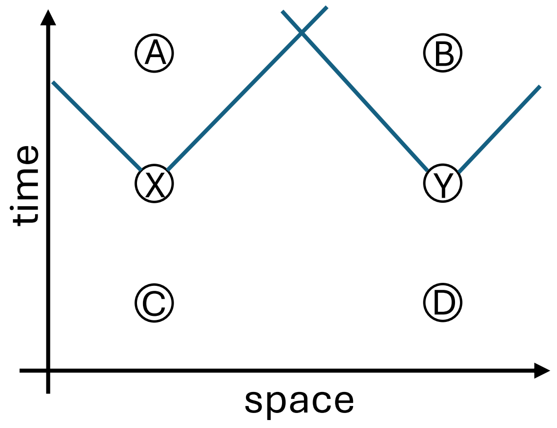
$$= \left(\frac{1}{\sqrt{3}} \langle H|_C \otimes \langle \downarrow|_S + \sqrt{\frac{2}{3}} \langle T|_C \otimes \langle \rightarrow|_S \right) \left(|-\rangle_C \langle -| \otimes |\downarrow\rangle_S \langle \downarrow| \right) \left(\frac{1}{\sqrt{3}} |H\rangle_C \otimes |\downarrow\rangle_S + \sqrt{\frac{2}{3}} |T\rangle_C \otimes |\rightarrow\rangle_S \right)$$

$$= \left(\frac{1}{\sqrt{3}} \langle H|_C \otimes \langle \downarrow|_S + \sqrt{\frac{2}{3}} \langle T|_C \otimes |\rightarrow\rangle_S \right) \left(\frac{1}{\sqrt{6}} |-\rangle_C \otimes |\downarrow\rangle_S - \frac{1}{2}\sqrt{\frac{2}{3}} |-\rangle_C \otimes |\downarrow\rangle_S \right)$$

$$= \frac{1}{\sqrt{36}} - \frac{1}{6} - \frac{1}{\sqrt{36}} + \frac{1}{6} = 0$$

Bonus Extended Wigner's Friend

In the paper **"A Strong No-Go Theorem on the Wigner's Friend Paradox"**, they consider another extended Wigner's friend experiment and prove that another of three conditions *must be false.*



Absoluteness of observed events (AOE)	No Super-Determinism	Locality
Measurements recorded by agents are real events that occur regardless of other agents.	Measurements outcomes in the past are not correlated with measurement choices in the future.	Space-like separated measurement choices cannot influence other agents' probabilities of outcomes.
$\exists P(a,b,c,d),$ s.t. $P(a,b) = \sum_{c,d} P(a,b,c,d)$	$P(c,d \vert x,y) = P(c,d)$	$P(a \vert bcdxy) = P(a \vert bcdx)$ $P(b \vert acdxy) = P(b \vert acdy)$