Contextuality and system identification

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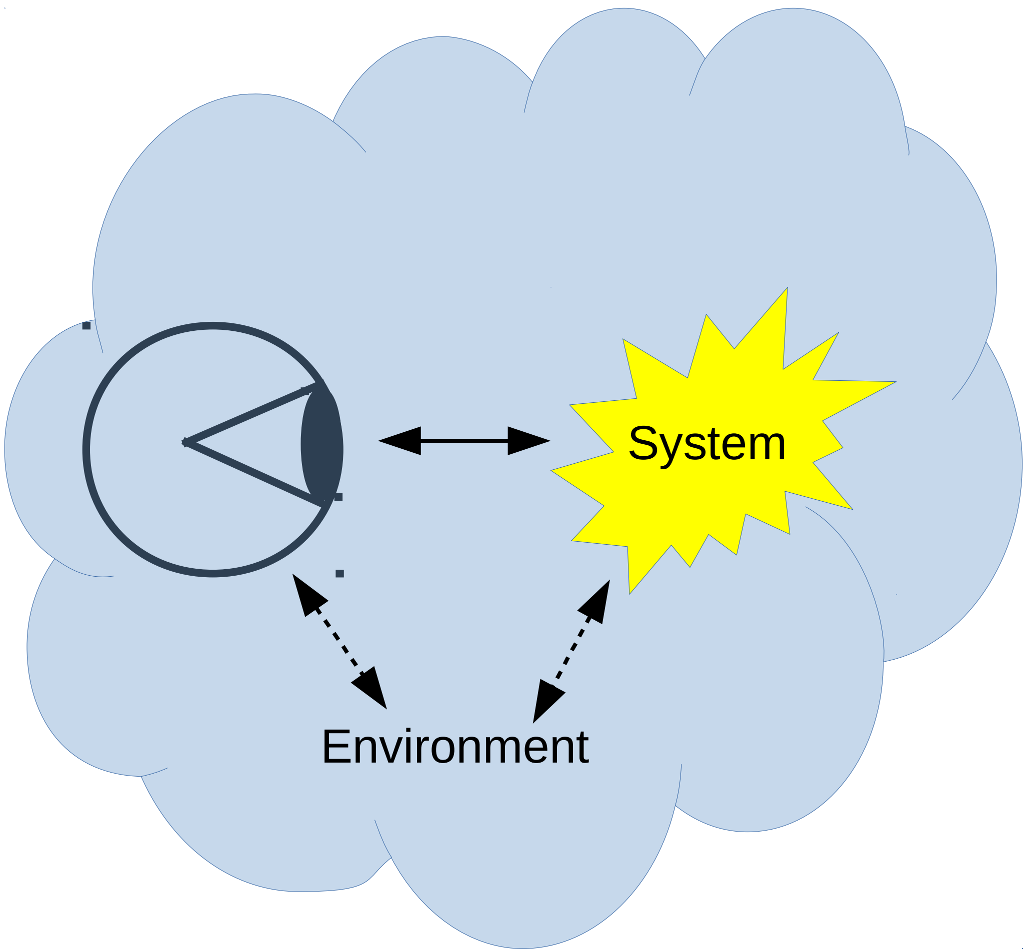
“Observation” in QT



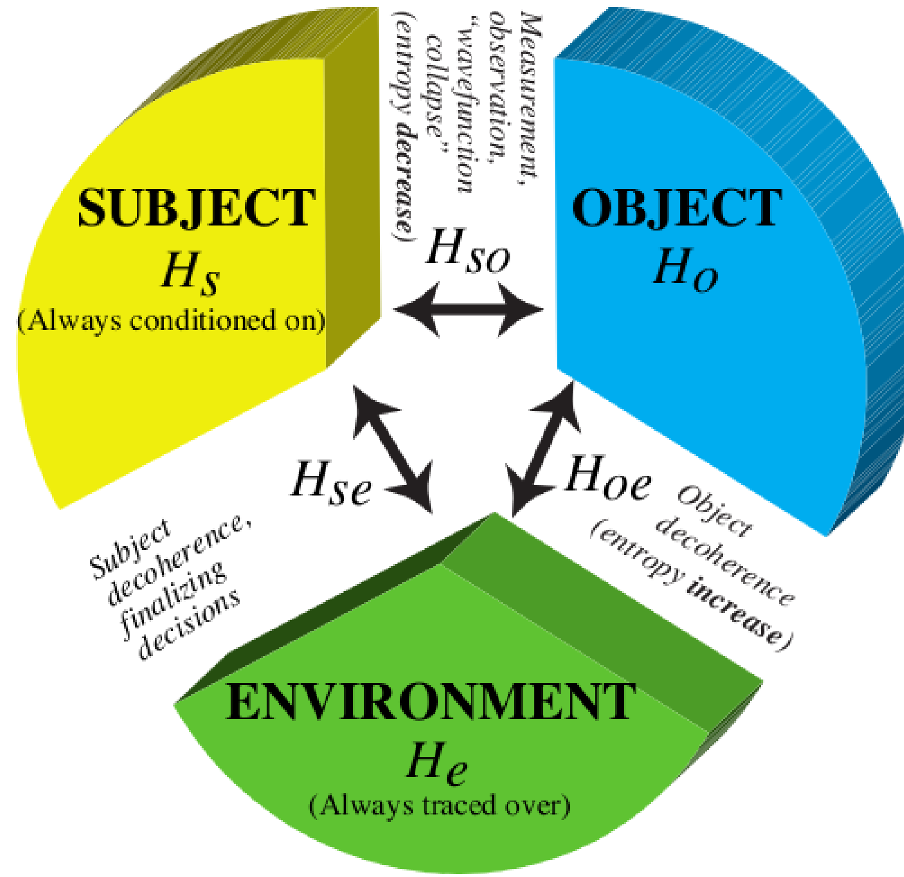


FIG. 2: An observer can always decompose the world into three subsystems: the degrees of freedom corresponding to her subjective perceptions (the subject), the degrees of freedom being studied (the object), and everything else (the environment). As indicated, the subsystem Hamiltonians H_s, H_o, H_e and the interaction Hamiltonians H_{so}, H_{oe}, H_{se} can cause qualitatively very different effects, providing a unified picture including both decoherence and apparent wave function collapse. Generally, H_{oe} increases entropy and H_{so} decreases entropy.

M. Tegmark, *Phys Rev* D, 2012

The “system” has already been singled out from the rest of the observed world.

A decomposition has been stipulated:

$$\mathcal{H}_{\text{world}} = \mathcal{H}_{\text{sys}} \otimes \mathcal{H}_{\text{env}}$$

Where does this decomposition come from?
How is the “right wire” identified?

Hilbert space decomposition is associative:

$\mathcal{H}_{\text{world}} = \mathcal{H}_1 \otimes (\mathcal{H}_2 \otimes \mathcal{H}_3) = (\mathcal{H}_1 \otimes \mathcal{H}_2) \otimes \mathcal{H}_3$

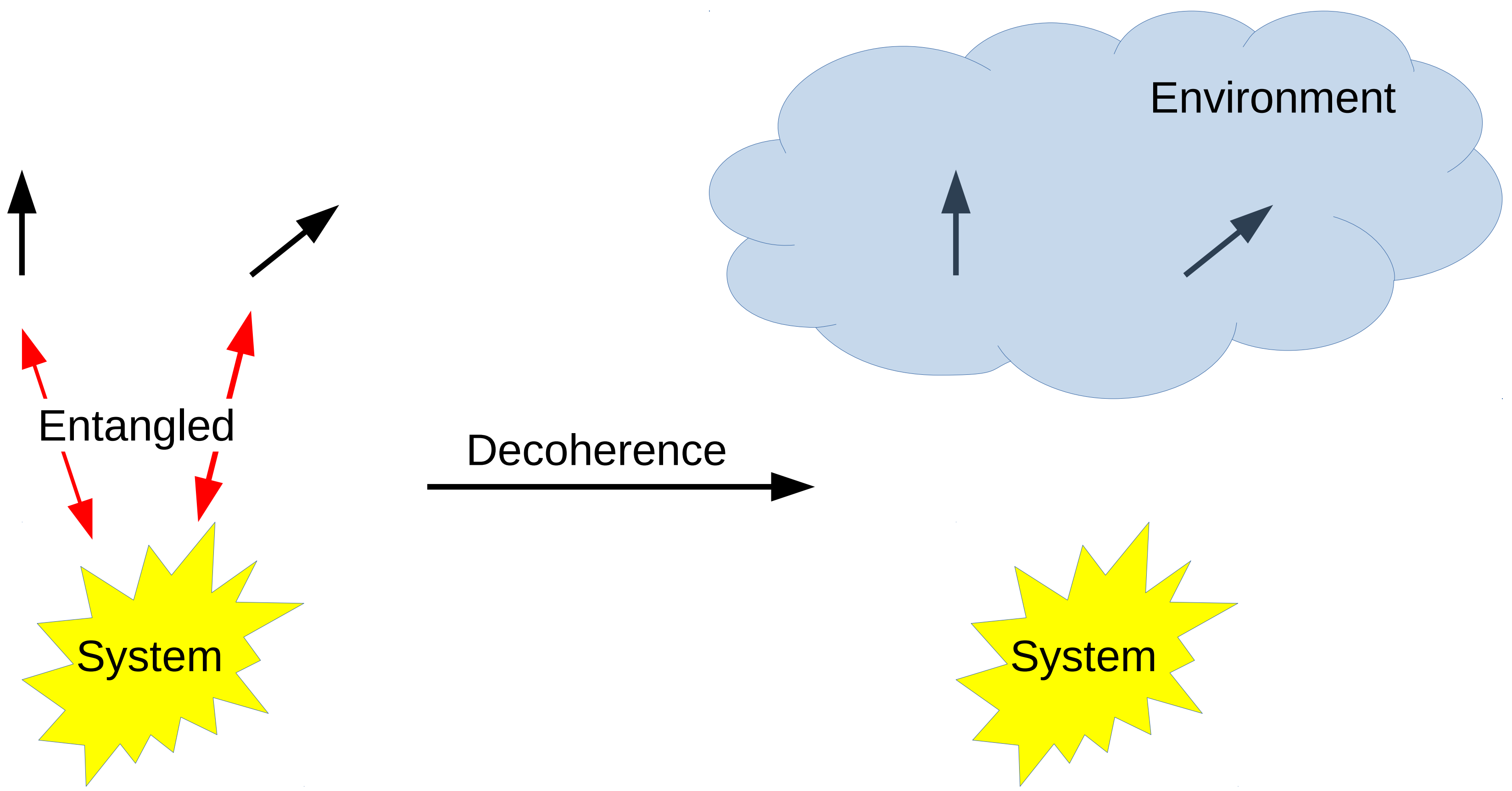
for any distinct $\mathcal{H}_1$, $\mathcal{H}_2$, $\mathcal{H}_3$ that jointly compose $\mathcal{H}_{\text{world}}$.

“Systems” aren’t given a priori.

We have to identify them, using our resources to separate them from the “background” of the world.

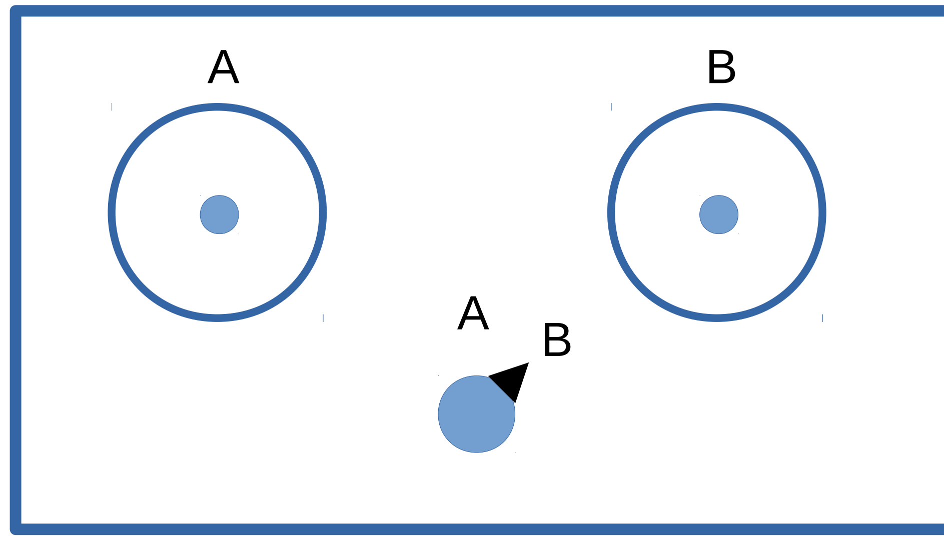
In quantum theory, the resource is a finite set of finite-resolution observables.

We typically say the system is entangled with some macroscopic “pointer degrees of freedom” that then decohere to “classical” states that we can record.



How do we project $\mathcal{H}_{\text{point}}$ out of $\mathcal{H}_{\text{env}}$?

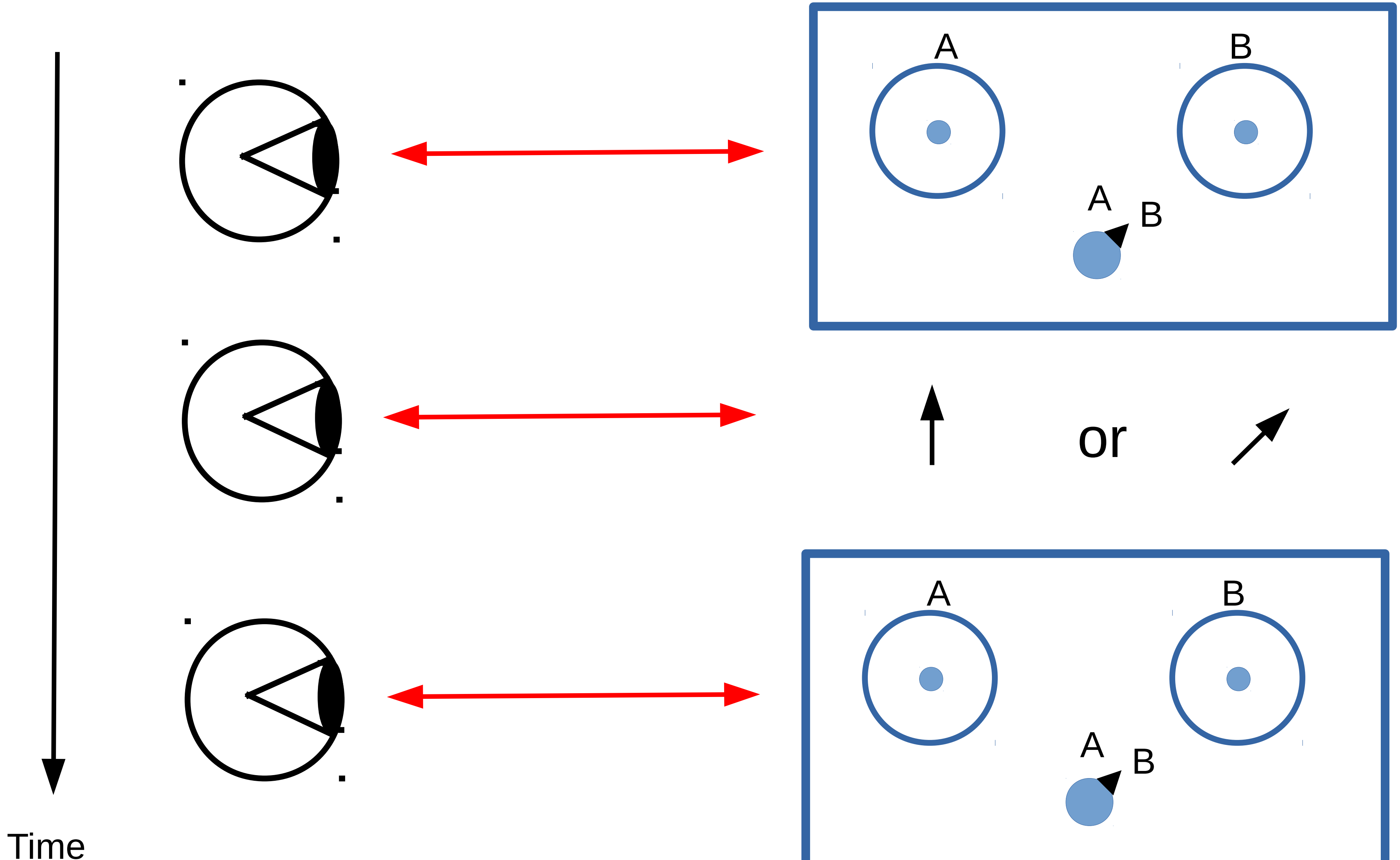
We project out a larger (but finite) part of $\mathcal{H}_{\text{env}}$ that we call the "apparatus" or the "laboratory."



We weakly couple its state (in $\mathcal{H}_{\text{app}}$) to the pointer state(s).

Then we impose a logical (or mereological) relation: interacting with the pointer(s) requires interacting with the apparatus. This interaction identifies the pointer(s).

So what we really have is *three* interactions.



Equivalently: Read then re-read a *label* associated with each pointer outcome.

Let $\mathcal{H}_{env'}$ be the remaining environment, $\mathcal{H}_{point} = \mathcal{H}_A \otimes \mathcal{H}_B$, and consider the decompositions for decoherence.

To observe |app>: $\mathcal{H}_{app} \otimes \overbrace{(\mathcal{H}_{env'} \otimes \mathcal{H}_A \otimes \mathcal{H}_B)}$

To observe |A>: $\mathcal{H}_A \otimes (\mathcal{H}_{env'} \otimes \mathcal{H}_{app} \otimes \mathcal{H}_B)$

To observe |B>: $\mathcal{H}_B \otimes \underbrace{(\mathcal{H}_{env'} \otimes \mathcal{H}_A \otimes \mathcal{H}_{app})}_{\text{Decohering environment}}$

At each step, the decohering environment is in a pure state that we do not observe and so trace over.

This is effectively a sequence of entanglement swaps.

Neglecting the never-observed |env’>, we have:

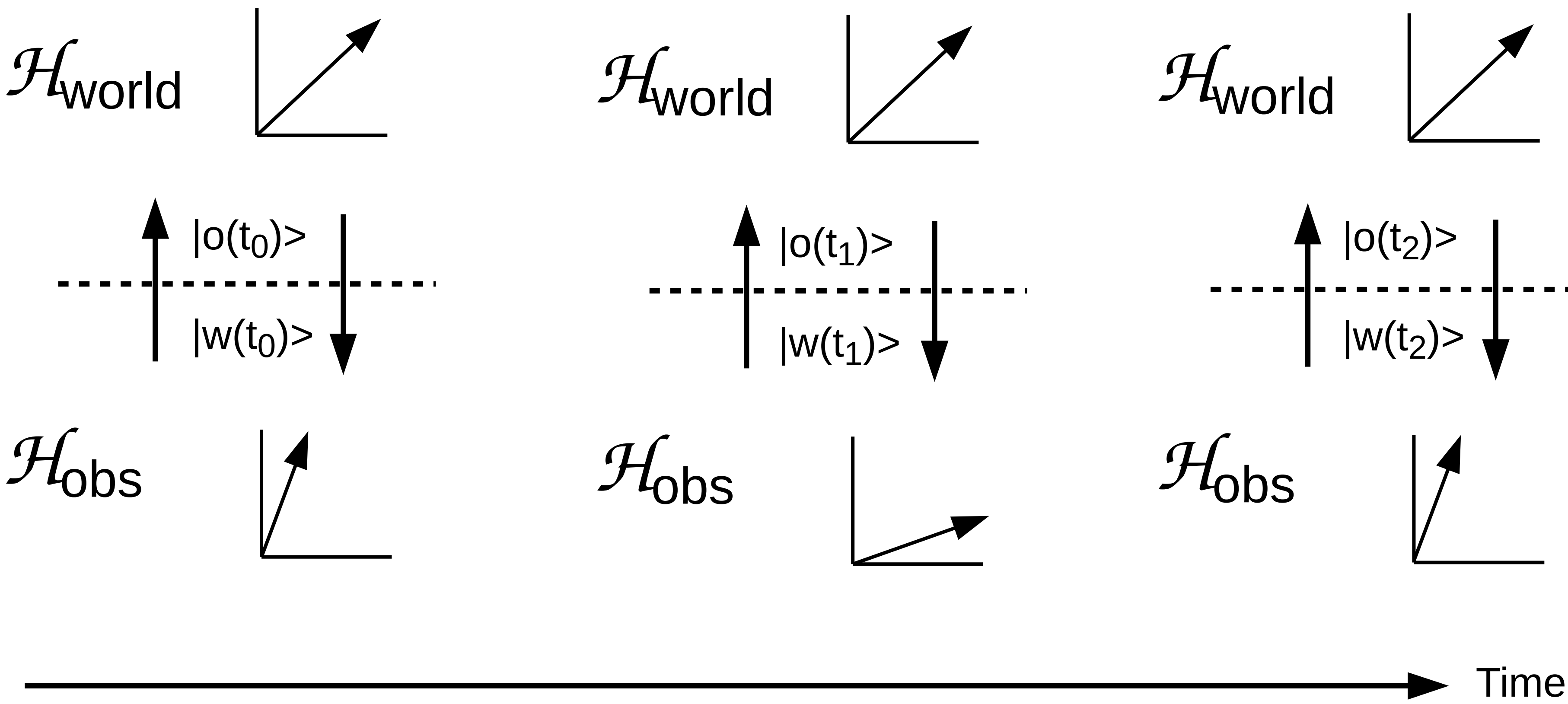
|AB> is not separable when |app> is observed;

|appB> is not separable when |A> is observed;

|appA> is not separable when |B> is observed;

Decoherence itself violates counterfactual definiteness when system identification is included explicitly.

These decompositional changes and entanglement swaps have no effect on the observable physics of the *world*:



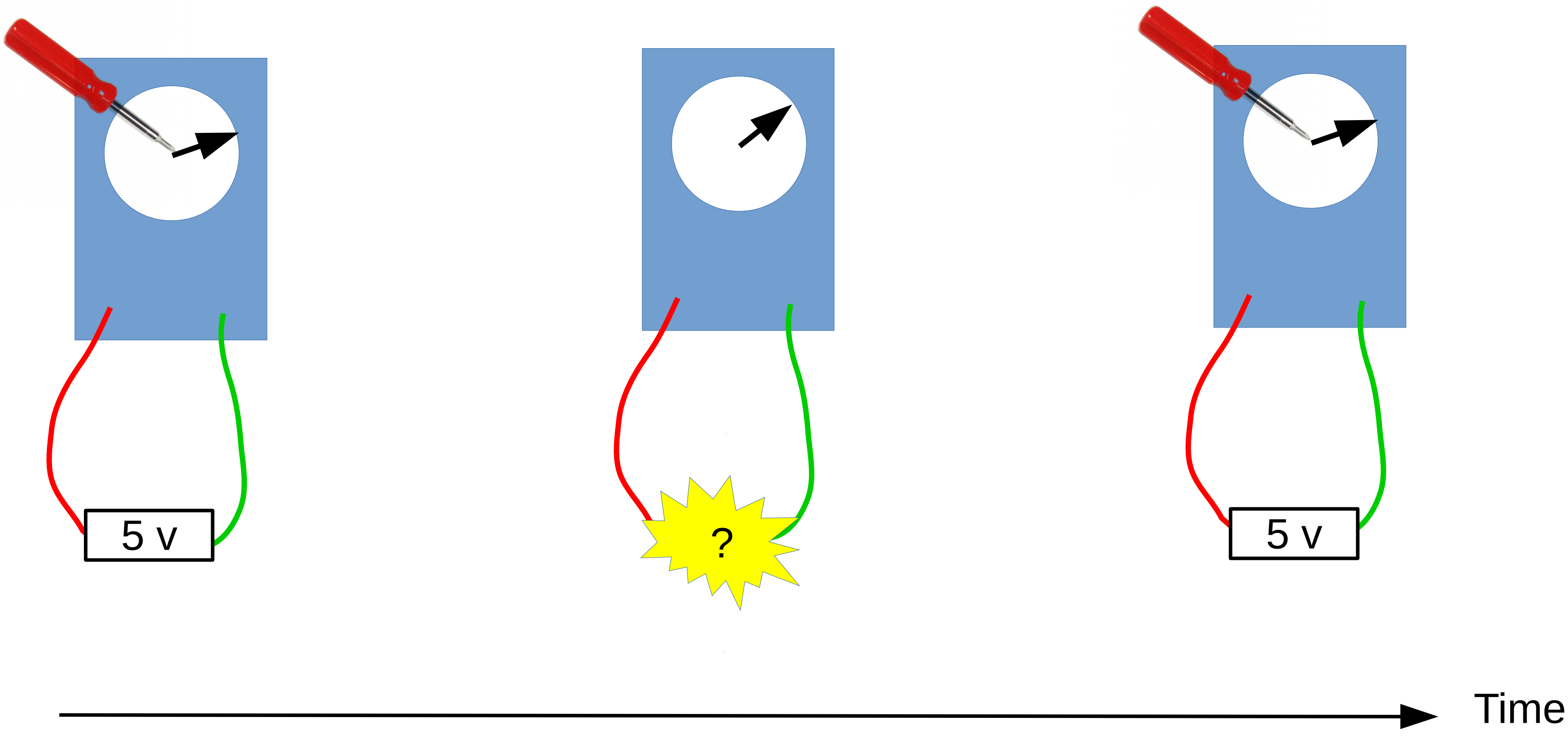
It’s only the physics in the *observer* that changes when the world’s decompositional boundaries are re-drawn.

To understand system identification, we have to understand the *internal* Hamiltonian H_{obs}, and we have to understand how changes in |obs> affect the interaction $H_{obs, world}$ and the outcomes it encodes.

It is H_{obs} that does the entanglement swap, so it is H_{obs} that introduces contextuality!

The observational outcome that $H_{obs, world}$ encodes on the observer – world boundary depends on |obs> and hence on the action of H_{obs}.

Classical analog: calibration



K. Krechmer, *Measurement*, 2016, 2018

Where does contextuality come from?

System identification is ambiguous with finite resources.

Complete isolation is not possible with finite resources.

The *finite cost of information to the observer* is the underlying problem.

Associatively decomposable state space	+	Finite information cost	=	Quantum Theory of *observation*

Thank you.

Questions?

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