On Formalisms and Interpretations

arXiv:1710.07212 [BW17]

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Philosophical Remarks

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what appears

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what is

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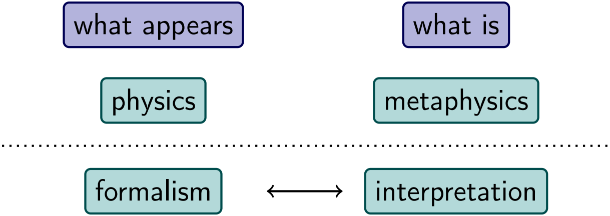
formalism

Philosophical Remarks

what appears	what is
physics	metaphysics
formalism	interpretation

Philosophical Remarks



Philosophical Remarks

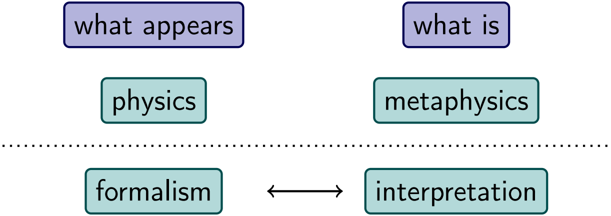
what appears — what is

physics — metaphysics

formalism ⟷ interpretation

- prediction of measurement results *(empirical equivalence)*

Philosophical Remarks



- prediction of measurement results *(empirical equivalence)*
- formalism $\neq$ interpretation

Philosophical Remarks

what appears | what is

physics | metaphysics

formalism $\longleftrightarrow$ interpretation

- prediction of measurement results *(empirical equivalence)*
- formalism $\neq$ interpretation
- classical: empirically equivalent formalisms $\rightarrow$ interpretation
  quantum: formalism $\rightarrow$?

Quantum Measurement 1

- Quantum system in state $|\phi\rangle$

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$$p_\phi(a) = \mathrm{Tr}(|a\rangle\langle a||\phi\rangle\langle\phi|) = |\langle a|\phi\rangle|^2 \tag{1}$$

Born rule

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Born rule

- Measurement update rule: *(collapse)*

$$|\phi\rangle \xrightarrow[\text{result: } a]{A} |a\rangle \qquad (2)$$

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Born rule

- Measurement update rule: *(collapse)*

$$|\phi\rangle \xrightarrow[\text{result: } a]{A} |a\rangle \tag{2}$$

...giving probabilities for *subsequent measurements*!

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$$|\phi\rangle = \sum_a \phi_a |a\rangle \mapsto \sum_a \phi_a |a\rangle \otimes |A\rangle = |\phi_{tot}\rangle \tag{3}$$

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- Probabilities of outcomes are probabilities of states of the observer:

$$q_\phi(a) = \mathrm{Tr}(\mathbb{1} \otimes |A\rangle\langle A||\phi_{tot}\rangle\langle\phi_{tot}|) \tag{4}$$

"Born" rule

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  - QBism

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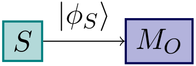

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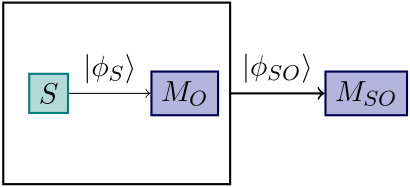

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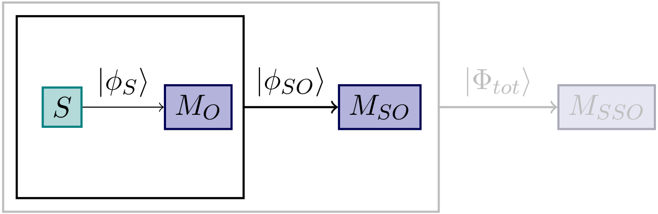
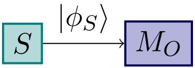


- *Observers* observing the same quantum *system*.
- *Superobservers* observing *systems and observers* as a joint system.
- *Super-superobservers* etc.

Same Level of Observation



Same Level of Observation

$$M_{O_1} : \{|\uparrow\rangle_S, |\downarrow\rangle_S\};\ M_{O_2} : \{|a\rangle_S, |b\rangle_S\}$$

...where $|\uparrow\rangle = \alpha|a\rangle + \beta|b\rangle$, $|\downarrow\rangle = \beta|a\rangle - \alpha|b\rangle$

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Probabilities in the Collapse Formalism

O_2 observing $c = a, b$, given O_1 observed $z = \uparrow, \downarrow$

$$p(c|z) = \mathrm{Tr}(|c\rangle\langle c||z\rangle\langle z|) = |\langle c|z\rangle|^2.$$

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- Collapse:

z	$p(a \mid z)$	$p(b \mid z)$
$\uparrow$	α^2	β^2
$\downarrow$	β^2	α^2

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Probabilities in the Relative State Formalism

O_2 observing $c = a, b$, given O_1 observed $z = \uparrow, \downarrow$

$$q(c|z) = \frac{1}{q_z} \mathrm{Tr}(\mathbb{1} \otimes |Z\rangle\langle Z| \otimes |C\rangle\langle C||\phi_{tot}\rangle\langle\phi_{tot}|).$$

Same Level of Observation

$$M_{O_1} : \{|\uparrow\rangle_S, |\downarrow\rangle_S\};\ M_{O_2} : \{|a\rangle_S, |b\rangle_S\}$$

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- Collapse:

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$\uparrow$	α^2	β^2
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- Relative state:

z	$q(a \mid z)$	$q(b \mid z)$
u	α^2	β^2
d	β^2	α^2

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$\uparrow$	α^2	β^2
$\downarrow$	β^2	α^2

empirically equivalent

- Relative state:

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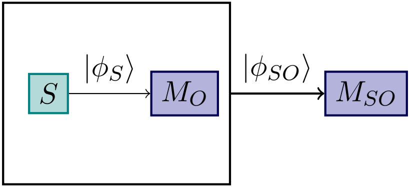
Different Levels of Observation



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- Relative state:

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D	$\left(\frac{\alpha+\beta}{2\beta}\right)^2$	$\left(\frac{\alpha-\beta}{2\alpha}\right)^2$

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empirically inequivalent

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Relative-state formalism is *empirically inequivalent* to collapse formalism.

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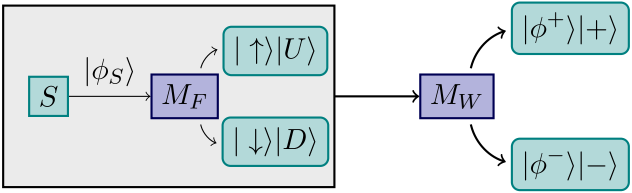
$$|\phi_S\rangle = \sqrt{\frac{1}{2}}(|\uparrow\rangle + |\downarrow\rangle)$$

$$|\phi^{\pm}\rangle = \sqrt{\frac{1}{2}}\,(|\uparrow, U\rangle \pm |\downarrow, D\rangle),\ \alpha = \beta = \sqrt{\frac{1}{2}}$$



Relative-state formalism is *empirically inequivalent* to collapse formalism.

Collapse

Z	$p(+ \mid Z)$	$p(- \mid Z)$	Is "$-$" possible?
U	$\frac{1}{2}$	$\frac{1}{2}$	yes
D	$\frac{1}{2}$	$\frac{1}{2}$	yes

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Relative State

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Relative-state formalism is *empirically inequivalent* to collapse formalism.

Friend

Z	$p(+ \mid Z)$	$p(- \mid Z)$	Is "$-$" possible?
U	$\frac{1}{2}$	$\frac{1}{2}$	yes
D	$\frac{1}{2}$	$\frac{1}{2}$	yes

Wigner

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Wigner

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Wigner's - friend paradox: Different agents use different formalisms for friend's measurement. *(subjective collapse)*

Formalisms and Interpretations

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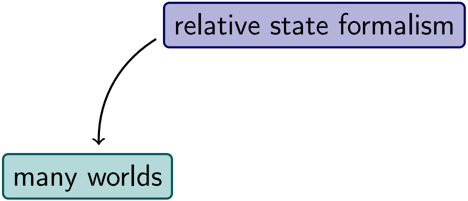

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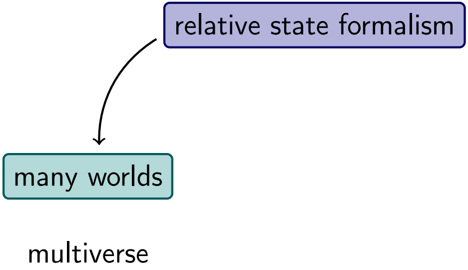

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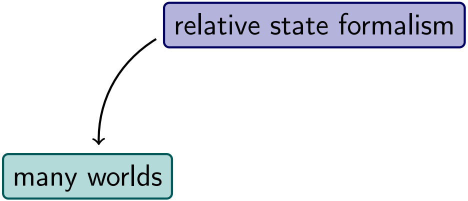

multiverse

deterministic evolution

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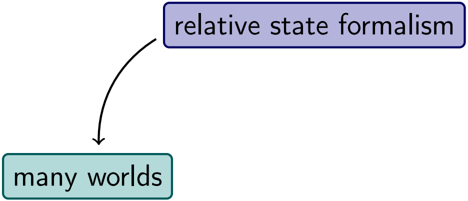

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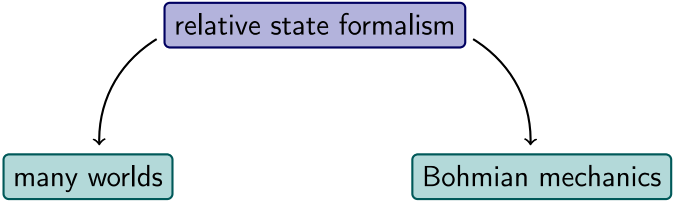

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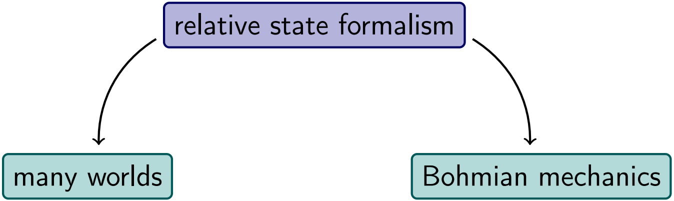

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pilot wave & real state vectors

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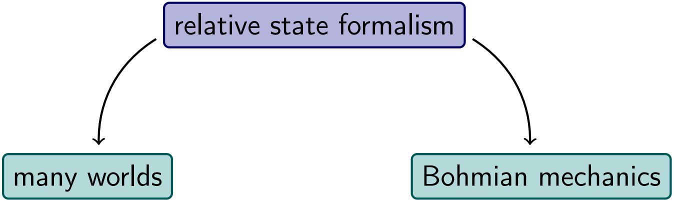

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Formalisms and Interpretations

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relative state formalism

many worlds	Bohmian mechanics
multiverse	pilot wave & real state vectors
deterministic evolution	probabilistic evolution
partially observable	fully observable

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collapse formalism

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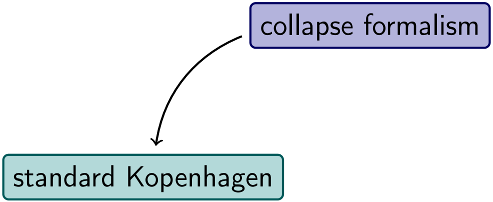

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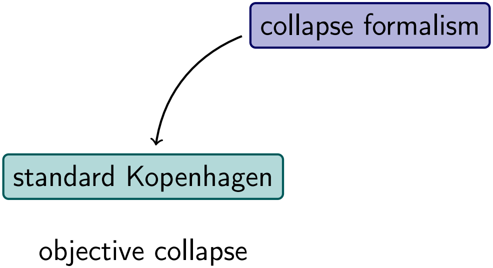

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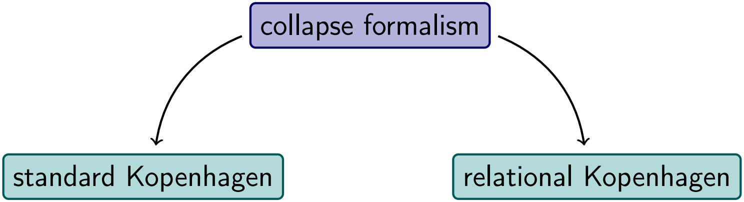

objective collapse

Formalisms and Interpretations

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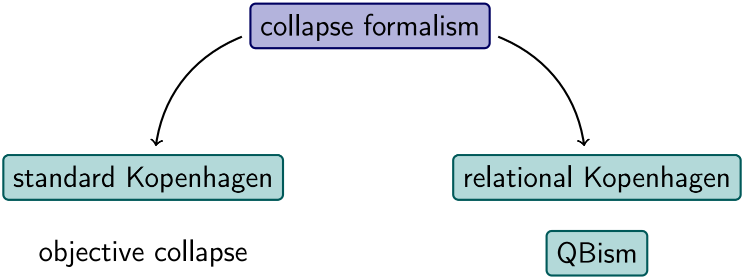

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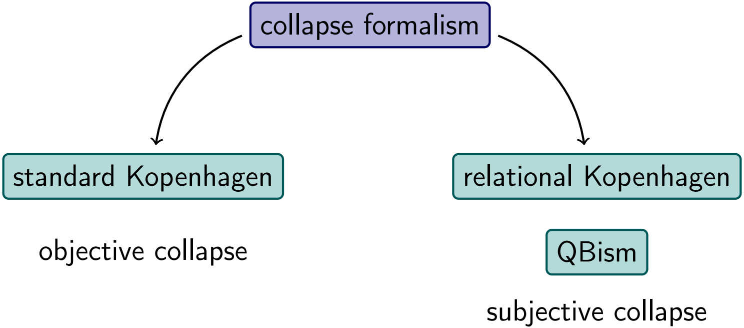

Relative-state formalism is *empirically inequivalent* to collapse formalism.

Friend

Z	$p(+ \mid Z)$	$p(- \mid Z)$	Is "$-$" possible?
U	$\frac{1}{2}$	$\frac{1}{2}$	yes
D	$\frac{1}{2}$	$\frac{1}{2}$	yes

Wigner

Z	$q(+ \mid Z)$	$q(- \mid Z)$	Is "$-$" possible?
U	1	0	no
D	1	0	no

Wigner's - friend paradox: Different agents use different formalisms for friend's measurement. *(subjective collapse)*

Contradictions for Encapsulated Observers

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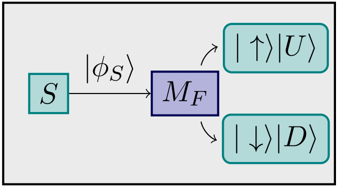

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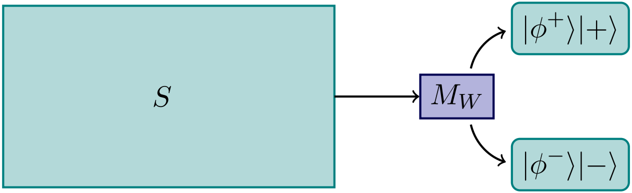

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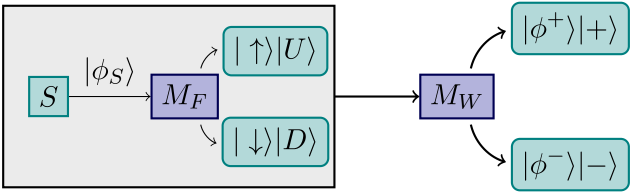

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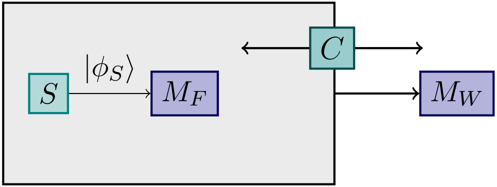

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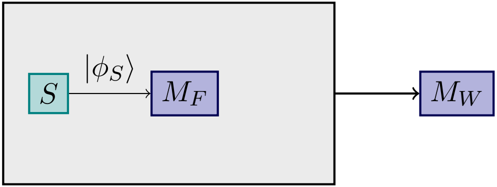

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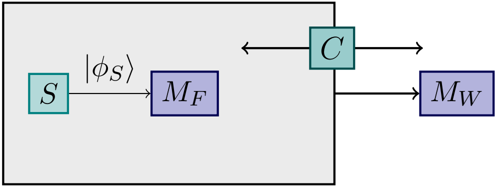

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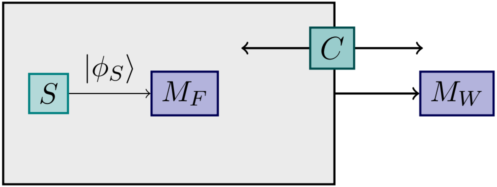

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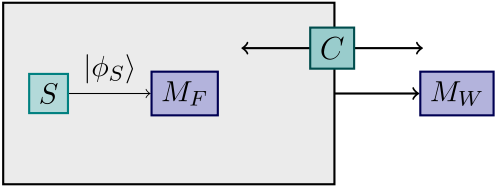

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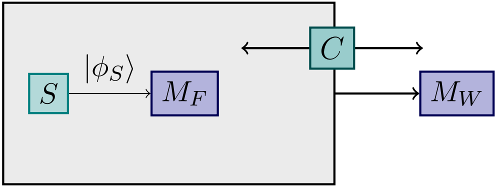

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Thank you!

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