The Modal Interpretation of Quantum Theory

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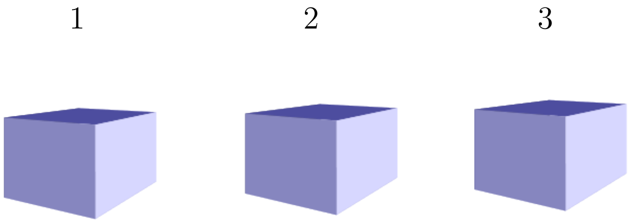
Main claim

The possibility structure is fixed in classical physics but changes with time in the modal interpretation of quantum theory

Concepts

- **Physical quantity:** velocity, energy, etc.
- **Ontic state:** assigns a definite value to all quantities
- **Possibility structure**: set of ontic states
- **Epistemic state:** distribution of the ontic states
- **Dynamics:** evolution of the ontic/epistemic state

Ball in the box



Classical case

Opening any two boxes, we always find either $\bullet\ \bullet$ or $\circ\ \circ$ with probability $\frac{1}{2}$ each

Classical case

$$
\begin{aligned}
p(\bullet\ \bullet \mid 1\,2\,) &= \frac{1}{2} \\
&\cdots \\
&\cdots
\end{aligned}
$$

Classical case

Ontic states:

$$\begin{array}{ccc} \boxed{1} & \boxed{2} & \boxed{3} \\ \bullet & \bullet & \bullet \\ \circ & \circ & \circ \end{array}$$

Epistemic state:

$$\frac{1}{2}\left(\bullet \quad \bullet \quad \bullet\right) + \frac{1}{2}\left(\circ \quad \circ \quad \circ\right)$$

Classical case

Explanation:

$$p(\bullet\ \bullet \,|\, 1\, 2\,) = p(\bullet\ \bullet\ \mathrm{x}\,) = p(\bullet\ \bullet\ \bullet\,) = \frac{1}{2}$$

Classical case

Epistemic change:

$$\frac{1}{2}\,(\bullet \quad \bullet \quad \bullet) \;+\; \frac{1}{2}\,(\circ \quad \circ \quad \circ) \qquad \xrightarrow{\text{Measurement}} \qquad (\bullet \quad \bullet \quad \bullet)$$

Quantum case

Opening any two boxes, we always find either $\bullet \circ$ or $\circ \bullet$ with probability $\frac{1}{2}$ each

Quantum case

$$
\begin{aligned}
p(\bullet\ \circ \mid 1\,2) &= \frac{1}{2} \\
&\cdots \\
&\cdots
\end{aligned}
$$

Realism

Ontic states:

$$\begin{array}{ccc} \boxed{1} & \boxed{2} & \boxed{3} \\ \bullet & \circ & ? \end{array}$$

No trivial ontic states

Realism

Ontic states:

$$\boxed{1} \quad \boxed{2} \quad \boxed{3}$$

$$\bullet \quad \bullet \quad \bullet$$

$+$ Causal mechanism: the ball in the box opened later turns white

Realism

Problem: nonlocal ontic change

$$(\bullet \quad \bullet \quad \bullet) \qquad \xrightarrow{\text{Measurement}} \qquad (\bullet \quad \circ \quad \bullet)$$

Operationalism

$$p(\bullet \circ \mid 1\,2) = \frac{1}{2}$$

$$\cdots$$

$$\cdots$$

Orthodoxy

Ontic states: propensities

$$\boxed{1} \quad \boxed{2} \quad \boxed{3}$$

●○ ●○ ●○

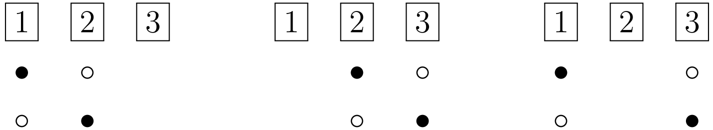
Orthodoxy

Problem: nonlocal ontic change

$$(\bullet\circ \quad \bullet\circ \quad \bullet\circ) \xrightarrow{\text{Measurement}} (\bullet \quad \circ \quad \bullet\circ)$$

Modal

Ontic states:



Modal

Epistemic change:

$$\frac{1}{2}\left(\bullet \ \circ \quad\right) + \frac{1}{2}\left(\circ \ \bullet \quad\right) \qquad \xrightarrow{\text{Measurement}} \qquad \left(\bullet \ \circ \quad\right)$$

Modal

Problem: nonlocal ontic change

$$\text{Opening } \boxed{1} \;\; \boxed{2} \qquad \longrightarrow \qquad \frac{1}{2}\,(\bullet \;\circ \quad\;) + \frac{1}{2}\,(\circ \;\bullet \quad\;)$$

$$\text{Opening } \boxed{1} \;\; \boxed{3} \qquad \longrightarrow \qquad \frac{1}{2}\,(\bullet \quad\; \circ) + \frac{1}{2}\,(\circ \quad\; \bullet)$$

Possibility structure

Classical case

One possibility structure:

$\boxed{1}$	$\boxed{2}$	$\boxed{3}$
$\bullet$	$\bullet$	$\bullet$
$\bullet$	$\bullet$	$\circ$
$\bullet$	$\circ$	$\bullet$
$\circ$	$\bullet$	$\bullet$
$\bullet$	$\circ$	$\circ$
$\circ$	$\bullet$	$\circ$
$\circ$	$\circ$	$\bullet$
$\circ$	$\circ$	$\circ$

Epistemic state:

$$\frac{1}{2}\left(\bullet \quad \bullet \quad \bullet\right) + \frac{1}{2}\left(\circ \quad \circ \quad \circ\right)$$

Operationalism

No possibility structure

Orthodoxy

One possibility structure:

$\boxed{1}$	$\boxed{2}$	$\boxed{3}$
●○	●○	○●
●○	○●	●○
○●	●○	●○
●○	○●	○●

...

Epistemic state:

p_1 (●○ ●○ ●○) + p_2 (○● ○● ●○) + ...

Modal

Three possibility structures:

$\boxed{1}$	$\boxed{2}$	$\boxed{3}$
$\bullet$	$\bullet$	
$\bullet$	$\circ$	
$\circ$	$\bullet$	
$\circ$	$\circ$	

$\boxed{1}$	$\boxed{2}$	$\boxed{3}$
	$\bullet$	$\bullet$
	$\bullet$	$\circ$
	$\circ$	$\bullet$
	$\circ$	$\circ$

$\boxed{1}$	$\boxed{2}$	$\boxed{3}$
$\bullet$		$\bullet$
$\bullet$		$\circ$
$\circ$		$\bullet$
$\circ$		$\circ$

Epistemic states:

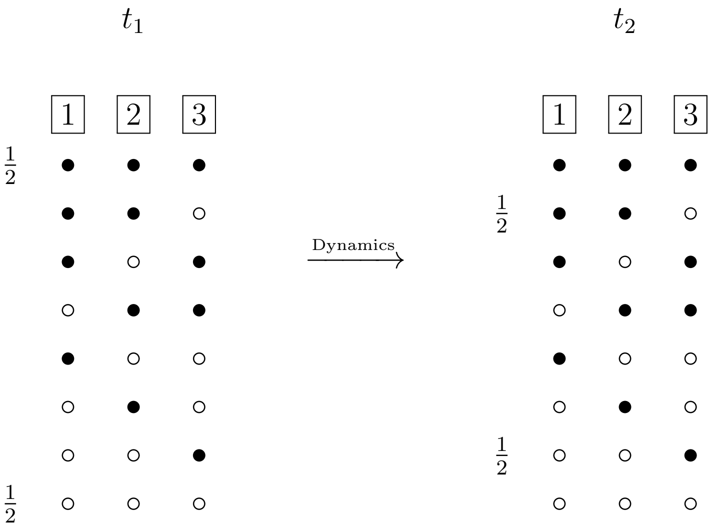
$$\frac{1}{2}(\bullet\ \circ\ \quad) + \frac{1}{2}(\circ\ \bullet\ \quad)$$

$$\frac{1}{2}(\quad \bullet\ \circ) + \frac{1}{2}(\quad \circ\ \bullet)$$

$$\frac{1}{2}(\bullet\ \quad \circ) + \frac{1}{2}(\circ\ \quad \bullet)$$

Dynamics

Classical physics



Quantum theory

t_1

	$\boxed{1}$	$\boxed{2}$	$\boxed{3}$
	●	●	
$\frac{1}{2}$	●	○	
$\frac{1}{2}$	○	●	
	○	○	

$\xrightarrow{\text{Dynamics}}$

t_2

	$\boxed{1}$	$\boxed{2}$	$\boxed{3}$
$\frac{1}{2}$		●	●
		●	○
		○	●
$\frac{1}{2}$		○	○

Conclusions: classical physics

- **Ontic state:** assigns a definite value to all physical quantities
- **Possibility structure**: set of ontic states
- **Epistemic state:** probability distribution over the ontic states
- The possibility structure is **fixed**

Conclusions: quantum theory

- We want to interpret the **quantum state epistemically**
- For this, we need **ontic states**
- But there is **no ontic state** assigning a definite value to **all** physical quantities
- **Solution: Restrict** the set of physical quantities which have a definite value at a given time
- **Ontic state** will assign a definite value to **these** quantities
- Hence, the quantum state will be **epistemic**: a probability distribution over **these** ontic states

Conclusions: quantum theory

- The possibility structure that is the set of ontic states will **depend on** the quantum state
- The quantum state **evolves** according to the quantum dynamics
- The possibility structure will be **changing in time**

References

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Conclusions

- Classically, the (epistemic) state of the system is a probability distribution over the possible (dispersion-free) ontic states (2-valued homomorphisms) on the Boolean algebra generated from the subspaces of the phase space
- Each 2-valued homomorphism assigning a definite value to all physical quantities represent a physical possibility
- This possibility structure is fixed

Conclusions

- In quantum mechanics, there are no (disperion-free) ontic states (2-valued homomorphisms) on the Hilbert lattice (Kochen-Specker theorem, Gleason's theorem)
- To interpret the quantum state epistemically as a probability distribution over the ontic states, we need to restrict the Hilbert lattice to a determinate sublattice (a partial Boolean algebra)
- The set of 2-valued homomorphism over this sublattice representing the possibility structure of quantum theory changes with time