On Einstein’s Reality Criterion

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Reality Criterion (RC):

“If, without in any way disturbing a system, we can predict with certainty (i.e. with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.”
Main messages:

1. The EPR argument, making use of the RC, is devised to prove *incompleteness*, whereas Einstein’s latter arguments, not using the RC, are to prove *unsoundness*.

2. The RC is a special case of Reichenbach’s Common Cause Principle and also of Bell’s Local Causality Principle.
I. Interpretations of QM in a systematic way
II. The EPR argument and Einstein’s latter arguments
III. What is Einstein’s Reality Criterion?
I. Interpretations of QM
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\[ A_1^1 \]
\[ a_1 \]

\[ A_2^6 \]
\[ a_2 \]

\[ A_1^2 \]
\[ a_1 \]
I. Interpretations of QM

What is a measurement?

- Measurement settings: \( a_m \)
- Measurement outcomes: \( A_m^i \)
- Probability = long run relative frequency:

\[
p(A_m^i | a_m) = \frac{\#(A_m^i \land a_m)}{\#(a_m)}
\]
I. Interpretations of QM

Minimal Interpretation (MI):
- Posited ontology: $a_m, A^i_m$
- Born rule:

$$\text{Tr}(WP^i) = p(A^i_m|a_m)$$
I. Interpretations of QM

Property Interpretation (PI):

- Posited ontology: $a_m, A^i_m, \alpha^i_m$
- Properties: $\alpha^i_m$

$$p(A^i_m | a_m \land \alpha^j_m) = \delta_{ij}$$
Copenhagen Interpretation (CI):

- Posited ontology: \( a_m, A^i_m, \omega, \omega^i_m \)

- Wave function: \( \omega, \omega^i_m \)

\[
p(A^i_m | a_m \land \omega) = \text{Tr}(W P^i)
\]

\[
p(A^i_m | a_m \land \omega^j_n) = \text{Tr}(W^j_n P^i)
\]

where \( W^j_n = \frac{P^j_n W P^j_n}{\text{Tr}(P^j_n W P^j_n)} \)
I. Interpretations of QM

The ontology posited by the different interpretations:

<table>
<thead>
<tr>
<th>MI:</th>
<th>outcomes $A^i_m$ &amp; settings $a_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI:</td>
<td>outcomes $A^i_m$ &amp; settings $a_m$ &amp; properties $\alpha^i_m$</td>
</tr>
<tr>
<td>CI:</td>
<td>outcomes $A^i_m$ &amp; settings $a_m$ &amp; wave function $\omega, \omega^i_m$</td>
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</table>
II. The EPR and Einstein’s latter arguments
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Completeness and soundness:

<table>
<thead>
<tr>
<th>Ontology of the world</th>
<th>of the theory</th>
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<tbody>
<tr>
<td>Completeness:</td>
<td>$\subseteq$</td>
</tr>
<tr>
<td>Soundness:</td>
<td>$\supseteq$</td>
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Ontology of the real world: posited by principles independent of the theory
# II. The EPR and Einstein’s latter arguments

**Main message:**

<table>
<thead>
<tr>
<th></th>
<th>EPR argument</th>
<th>Einstein’s latter arguments</th>
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<tr>
<td>MI:</td>
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<td>—</td>
</tr>
<tr>
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<td>✓</td>
<td>—</td>
</tr>
<tr>
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II/a. The EPR argument
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\begin{itemize}
  \item $A_1^5 \quad a_1$
  \item $B_1^1 \quad b_1$
  \item $A_2^6 \quad a_2$
  \item $B_2^6 \quad b_2$
  \item $A_1^4 \quad a_1$
  \item $B_3^3 \quad b_3$
\end{itemize}
II/a. The EPR argument

\begin{align*}
\text{A}_1^5 & : a_1 \\
\text{A}_2^6 & : a_2, \text{C}_2^6 \\
\text{A}_4^4 & : a_1 \\
\text{B}_1^1 & : b_1 \\
\text{B}_2^6 & : b_2 \\
\text{B}_3^3 & : b_3
\end{align*}
Elements of reality: $\mathcal{C}_m^i$

$$p(A^i_m | a_m \land C^j_m) = \delta_{ij}$$

- Elements of reality are properties
II/a. The EPR argument

Completeness: the elements of reality are contained in the ontology of the interpretation.
II/a. The EPR argument

Completeness: the elements of reality are contained in the ontology of the interpretation.

MI: incomplete
PI: ✓
CI: incomplete
II/b. Einstein’s latter arguments
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Einstein, 1936:

“Consider a mechanical system consisting of two partial systems A and B . . . Let us now determine the physical state of the partial system A as completely as possible by measurements. Then quantum mechanics allows us to determine the $\psi$ function of the partial system B from the measurements made, and from the $\psi$ function of the total system. This determination, however, gives a result which depends upon which of the physical quantities (observables) of A have been measured. Since there can be only one physical state of B after the interaction which cannot reasonably be considered to depend on the particular measurement we perform on the system A separated from B it may be concluded that the $\psi$ function is not unambiguously coordinated to the physical state.”
Einstein, 1936:

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II/b. Einstein’s latter arguments

**Soundness:** the ontology of the interpretation supervenes on the ontology of the real world.
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MI: —

PI: —

CI: unsound
### II. The EPR and Einstein’s latter arguments

**What do the arguments show?**

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III. What is Einstein’s Reality Criterion?
Main message: The Reality Criterion is a special case of Reichenbach’s Common Cause Principle and also of Bell’s Local Causality Principle.
III. What is Einstein’s Reality Criterion?

Prediction:

- A prediction is an event which stands in (ideally strong) correlation with another event.
- The predicted event is not causally relevant for the predicting event.
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Prediction:
- A prediction is an event which stands in (ideally strong) correlation with another event.
- The predicted event is not causally relevant for the predicting event.

RC adds:
- “without in any way disturbing a system”: neither the predicting event is causally relevant for the predicted event.
- “predict with certainty”: the correlation between the two events is perfect.
III/a. Common Cause Principle

Common Cause Principle:

- If there is a correlation between two events and there is no direct causal connection between the correlating events, then there always exists a common cause of the correlation.
Common Cause Principle:

- If there is a correlation between two events and there is no direct causal connection between the correlating events, then there always exists a common cause of the correlation.

Therefore:

- The RC is a special case of the Common Cause Principle when the correlation is (i) a prediction and (ii) is perfect.
- For perfect correlation the common cause will be deterministic (a property).
Local Causality Principle:
Local Causality Principle:

Therefore:

- The RC is a special case of the Local Causality Principle.
- Bonus: elements of reality are also localized.
Conclusions

The RC is not an analytic truth but a general metaphysical principle.

- The EPR argument, using the RC, is devised to prove incompleteness, whereas Einstein’s latter arguments, not using the RC, are to prove unsoundness.

- The RC is a special case of the Common Cause Principle and also of Local Causality.
References


