Title: On the Preparation of States in Nonlinear Quantum Mechanics

Date: Jun 28, 2012 11:30 AM

URL: http://pirsa.org/12060048

Abstract: Recent analysis of closed timelike curves from an information-theoretic perspective has led to contradictory conclusions about their information-processing power. One thing is generally agreed upon, however, which is that if such curves exist, the quantum-like evolution they imply would be nonlinear, but the physical interpretation of such theories is still unclear. It is known that any operationally verifiable instance of a nonlinear, deterministic evolution on some set of pure states makes the density matrix inadequate for representing mixtures of those pure states. We re-cast the problem in the language of operational quantum mechanics, building on previous work to show that the no-signalling requirement leads to a splitting of the equivalence classes of preparation procedures. This leads to the conclusion that any non-linear theory satisfying certain minimal conditions must be regarded as inconsistent unless it contains distinct representations for the two different kinds of mixtures, and incomplete unless it contains a rule for determining the physical preparations associated with each type. We refer to this as the `preparation problem' for nonlinear theories.

The Preparation Problem in Nonlinear Extensions of Quantum Theory

Nicolas C. Menicucci

The University of Sydney

E. G. Cavalcanti, NCM, and J. L. Pienaar, arXiv:1206.2725 [quant-ph]

The Preparation Problem in Nonlinear Extensions of Quantum Theory

Nicolas C. Menicucci

The University of Sydney

E. G. Cavalcanti, NCM, and J. L. Pienaar, arXiv:1206.2725 [quant-ph]

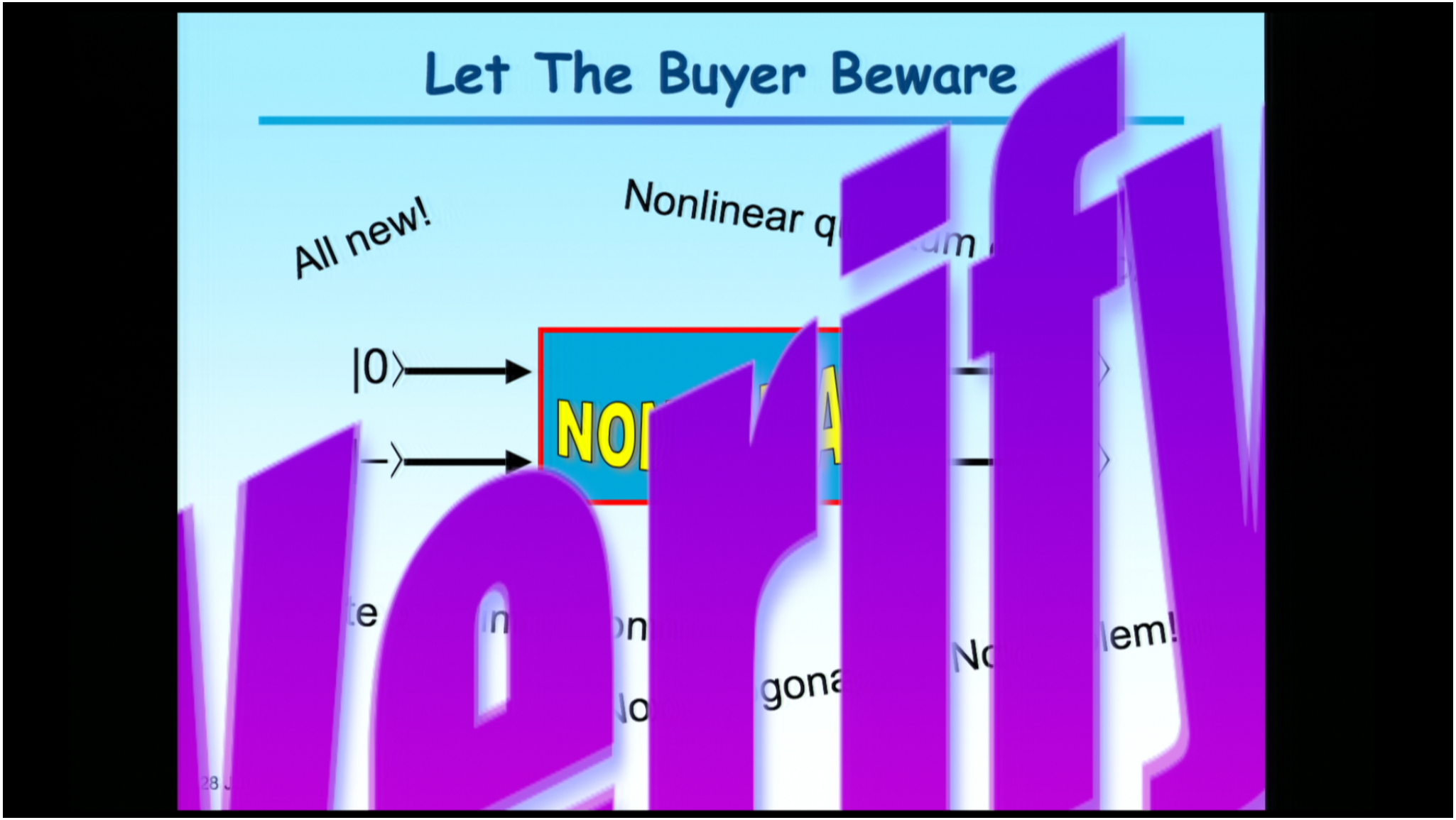
Let The Buyer Beware

All new!

Nonlinear quantum evolution!

State discrimination!

No orthogonality? No problem!


Let The Buyer Beware
All new!
Nonlinear q
|0⟩
NO
gona
lem!

Let The Buyer Beware

Let The Buyer Beware

Case 1: “You can only put in $|0\rangle$.”

28 Jun 2012

3

Let The Buyer Beware

Case 2: “You can only put in $|-\rangle$.”

28 Jun 2012

4

Let The Buyer Beware

Case 3: “You must alternate between $|0\rangle$ and $|-\rangle$.”

Let The Buyer Beware

Case 3: “You must alternate between $|0\rangle$ and $|-\rangle$.”

Let The Buyer Beware

Case 5: “You can use any method you want* to choose your input state to be $|0\rangle$ or $|-\rangle$.”

(*Can be relaxed to a finite set of methods that “seem random enough.”)

Epistemology

- *How* we know what we (claim to) know
- Claims must be *verifiable*

Epistemology

- *How* we know what we (claim to) know
- Claims must be *verifiable*

Epistemology

- *How* we know what we (claim to) know
- Claims must be *verifiable*
- Unverifiable claims are not considered

Epistemology

- *How* we know what we (claim to) know
- Claims must be *verifiable*
- Unverifiable claims are not considered
- Requirements for verification do not depend on details of the physics but rather on the process of *logical reasoning* and *inference*

Epistemology

- *How* we know what we (claim to) know
- Claims must be *verifiable*
- Unverifiable claims are not considered
- Requirements for verification do not depend on details of the physics but rather on the process of *logical reasoning* and *inference*
  - Stay close to scientific method
- Can sometimes allow buyer to be fooled and still get meaningful results

Closed Timelike Curves (CTCs)

- Several models
  - Deutsch model (several forms)
  - Postselected teleportation model (P-CTCs)
- All involve nonlinear quantum evolution

Closed Timelike Curves (CTCs)

- Several models
  - Deutsch model (several forms)
  - Postselected teleportation model (P-CTCs)
- All involve nonlinear quantum evolution
  - Does not respect superposition principle
- Arguments about results in this context
  - State discrimination
  - Cloning
  - Computational speedup (classical and quantum)
  - Superluminal signaling

Closed Timelike Curves (CTCs)

- Several models
  - Deutsch model (several forms)
  - Postselected teleportation model (P-CTCs)
- All involve nonlinear quantum evolution
  - Does not respect superposition principle
- Arguments about results in this context
  - State discrimination
  - Cloning
  - Computational speedup (classical and quantum)
  - Superluminal signaling
- Nonlinear boxes have foundational implications apart from applications to CTCs

Closed Timelike Curves (CTC's)

- "Interpretations" of quantum theory
  - Strongly affect results

Closed Timelike Curves (CTC's)

- "Interpretations" of quantum theory
  - Strongly affect results
  - Empirically distinguishable in nonlinear theory
  - Often unstated assumption
  - Sometimes stated as fact (even worse!)
- More fundamental problem
  - Using *linear tools* in a *nonlinear theory* (e.g., density matrix)
  - Brun et al. (2009): can discriminate nonorthogonal states, but preferred decompositions of density matrices exist
  - Bennett et al. (2009): no preferred decompositions; cannot discriminate nonorthogonal states

Closed Timelike Curves (CTC's)

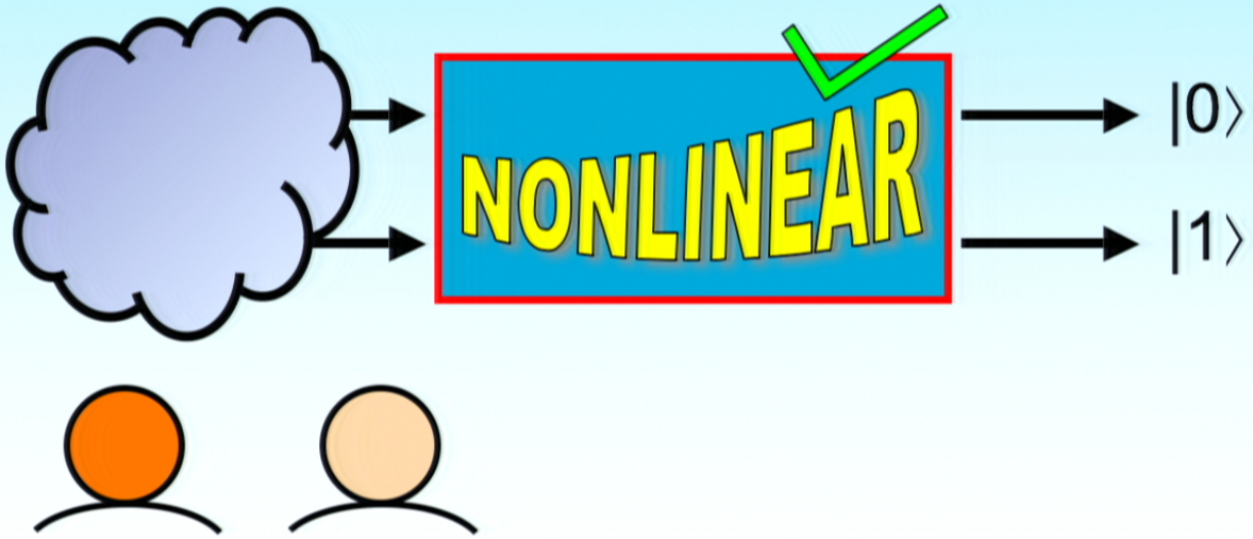
- "Interpretations" of quantum theory
  - Strongly affect results
  - Empirically distinguishable in nonlinear theory
  - Often unstated assumption
  - Sometimes stated as fact (even worse!)
- More fundamental problem
  - Using *linear tools* in a *nonlinear theory* (e.g., density matrix)
  - Brun et al. (2009): can discriminate nonorthogonal states, but preferred decompositions of density matrices exist
  - Bennett et al. (2009): no preferred decompositions; cannot discriminate nonorthogonal states

Ignorance

Alice's ignorance of the state *actually prepared* by Rob cannot ruin the evolution (by verifiability).

Ignorance

Alice's ignorance of the state *actually prepared* by Rob cannot ruin the evolution (by verifiability).



Is It Okay To Discriminate?

- Brun et al. (2009)
  - Claim nonlinear pure-to-pure evolution
  - *Can* discriminate nonorthogonal states
  - Preferred decompositions exist
  - Self-consistent!
- Bennett et al. (2009)

Is It Okay To Discriminate?

- Brun et al. (2009)
  - Claim nonlinear pure-to-pure evolution
  - *Can* discriminate nonorthogonal states
  - Preferred decompositions exist
  - Self-consistent!
- Bennett et al. (2009)
  - Claim nonlinear pure-to-pure evolution

Is It Okay To Discriminate?

- Brun et al. (2009)
  - Claim nonlinear pure-to-pure evolution
  - *Can* discriminate nonorthogonal states
  - Preferred decompositions exist
  - Self-consistent!
- Bennett et al. (2009)
  - Claim nonlinear pure-to-pure evolution
  - Use density matrix for proper mixture of input pure states
    - Troublesome, but not a show-stopper (see below)
  - Cannot discriminate pure states in purported evolution

Is It Okay To Discriminate?

- Brun et al. (2009)
  - Claim nonlinear pure-to-pure evolution
  - *Can* discriminate nonorthogonal states
  - Preferred decompositions exist
  - Self-consistent!
- Bennett et al. (2009)
  - Claim nonlinear pure-to-pure evolution
  - Use density matrix for proper mixture of input pure states
    - Troublesome, but not a show-stopper (see below)
  - Cannot discriminate pure states in purported evolution

All Pure States Created Equal?

All Pure States Created Equal?

All Pure States Created Equal?

"All pure states are created equal"

+

Verifiable nonlinear pure-to-pure evolution

All Pure States Created Equal?

"All pure states are created equal"

+

Verifiable nonlinear pure-to-pure evolution

All Pure States Not Created Equal?

Verifiable nonlinear pure-to-pure evolution

+

No superluminal signaling

Preparation Problem

- Type II pure states
  - These supposedly pure states are really just one "branch" of an entangled state that has not actually collapsed
  - Remotely preparable
  - Only reveal their purity to some parties
  - Attempting to remotely prepare a mixture of these states only creates an *improper mixture*, which has no preferred decomposition

Preparation Problem

- Type II pure states
  - These supposedly pure states are really just one "branch" of an entangled state that has not actually collapsed
  - Remotely preparable
  - Only reveal their purity to some parties
  - Attempting to remotely prepare a mixture of these states only creates an *improper mixture*, which has no preferred decomposition
  - Cannot be used to verify nonlinear pure-to-pure evolution (due to no-signaling requirement)

Preparation Problem

- The two types are indistinguishable in ordinary (linear) quantum theory
  - Distinction between them is deemed an "interpretational" question

Preparation Problem

- Preparations usually thought of as Type I
  - (Nondestructive) projective measurement
  - Cooling to ground state
  - Where do pure ancillas (for measurement) come from?
  - Where does low-entropy reservoir come from?

Preparation Problem

- Preparations usually thought of as Type I
  - (Nondestructive) projective measurement
  - Cooling to ground state
  - Where do pure ancillas (for measurement) come from?
  - Where does low-entropy reservoir come from?
- Preparations usually thought of as Type II
  - Projectively measure one arm of an EPR pair
  - Dynamic collapse models of quantum theory not ruled out
  - This would reduce these to Type I states in some cases
  - Speed of collapse? (state readout device [Kent, 2005])
- Deterministic versus random preparations

Preparation Problem

- Preparations usually thought of as Type I
  - (Nondestructive) projective measurement
  - Cooling to ground state
  - Where do pure ancillas (for measurement) come from?
  - Where does low-entropy reservoir come from?
- Preparations usually thought of as Type II
  - Projectively measure one arm of an EPR pair
  - Dynamic collapse models of quantum theory not ruled out
  - This would reduce these to Type I states in some cases
  - Speed of collapse? (state readout device [Kent, 2005])
- Deterministic versus random preparations
  - Alternative to the above distinction [Ralph and Myers, 2010]
  - Classical data written onto a quantum state verifies evolution
  - Random preparations (e.g., projection) do not

Summary

- Epistemology provides theory-independent consistency checks
  - Available by assumption of applicability of scientific method

Summary

- Epistemology provides theory-independent consistency checks
  - Available by assumption of applicability of scientific method
- If empirically meaningful, nonlinear evolution has "weird" effects that cannot be swept under the rug
- No signaling from verifiable nonlinear evolution implies Preparation Problem
  - Having a distinct mathematical representation for the different types of states is necessary (but not enough)
  - Also need to identify laboratory procedures that will produce each type of pure state
  - Dynamical collapse or a Heisenberg cut may provide a solution [Kent, 2005; Ralph and Myers, 2010]
  - Other ideas may be possible