Title: Towards a new ontological framework for quantum theory

Speakers: Lorenzo Catani

Series: Quantum Foundations

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Abstract: No-go theorems (Bell, Kochen-Specker, ...) formally show the departure of quantum theory from classical theory. These are formulated in the framework of ontological models and, if one accepts such framework, entail that quantum theory involves problematic ("fine-tuned") properties. I will argue that the lesson to take from the no-go theorems is to abandon the framework of ontological models as the way to model reality. I will analyze what I believe to be the unnatural assumptions of such framework and I will propose a way to change it. The basic principle of the new notion of reality I propose is that for something to exist is for something to be recorded. I will motivate the principle and explore its consequences. In order to implement such proposal into a precise theory-independent mathematical framework I will make use of point-free topological spaces (locales). I will discuss why this new proposal should be promising for understanding quantum theory and I will present several open questions.

Zoom link: https://pitp.zoom.us/j/91292006884?pwd=V2EzaEw5Z3NRUGd4cVdSRnlOOWFVZz09

# Towards a new ontological framework for quantum theory

**Lorenzo Catani**

31/01/2023

## Motivation

Get a better understanding of quantum theory

# Motivation

Direttore: Peter Gomez

Temi del Giorno CARLO NORDIO GIORNATA DELLA MEMORIA GUERRA RUSSIA UCRAINA MATTEO MESSIN

FQEXTRA • LA SEZIONE PREMIUM DEL FATTO QUOTIDIANO

IL PODCAST

I fatti di oggi, il Fatto di domani: 27 gennaio

VALENTINO È

Csm, Melo
sul candida

Qatargate, Giorgi e Figà-Talamanca restano i
carcere per un altro mese. Libere moglie e
figlia di Panzeri: parleranno con i giudici belg

Di F. Q.

**LE INDAGINI** – Magistrati belgi a Milano: hanno lavorato su pc e cellulari dei Panzeri

**COZZOLINO** – Ecco come ha cambiato la sue versione sulla mail pro-Qatar. Ora dice "non l'ho scritta io", ma al Fatto.it la rivendicò: "Mossa politica" (di G. Rosini)

Ucraina, raid sulla capitale. Kiev: "

# Motivation


IF YOU THINK YOU
UNDERSTAND
QUANTUM MECHANICS,
YOU DON'T
UNDERSTAND
QUANTUM MECHANICS

# Motivation

- Get a better understanding of QT.

  ↓

  Single out the inherently non-classical features.

- These features come from the comparison of QT and ontological models (no-go theorems).

$$\cancel{\text{Classical feature}} + \text{Ontological model framework} \neq \text{QT}$$

- These features unavoidably involve fine tunings.

## Motivation

### Fine tunings

Catani, Leifer, arXiv:2003.10050(2020).

Properties that hold at the level of the operational statistics predicted by the physical theory, but do not hold at the level of the model of reality associated to the theory.

## Motivation

### Fine tunings

Catani, Leifer, arXiv:2003.10050(2020).

Properties that hold at the level of the operational statistics predicted by the physical theory, but do not hold at the level of the model of reality associated to the theory.

No fine tuning related to "Leibnizianity" in Schmid, Selby, Spekkens, arXiv:2009.03297(2020).

# Motivation

- Fine tunings characterize nature with a conspiratorial connotation.

$$\text{Classical feature} + \text{Ontological model framework} \neq \text{QT}$$

# Motivation

## Goal

Develop a new theory-independent ontological framework that when compared with QT is absent of fine tunings.

# Outline

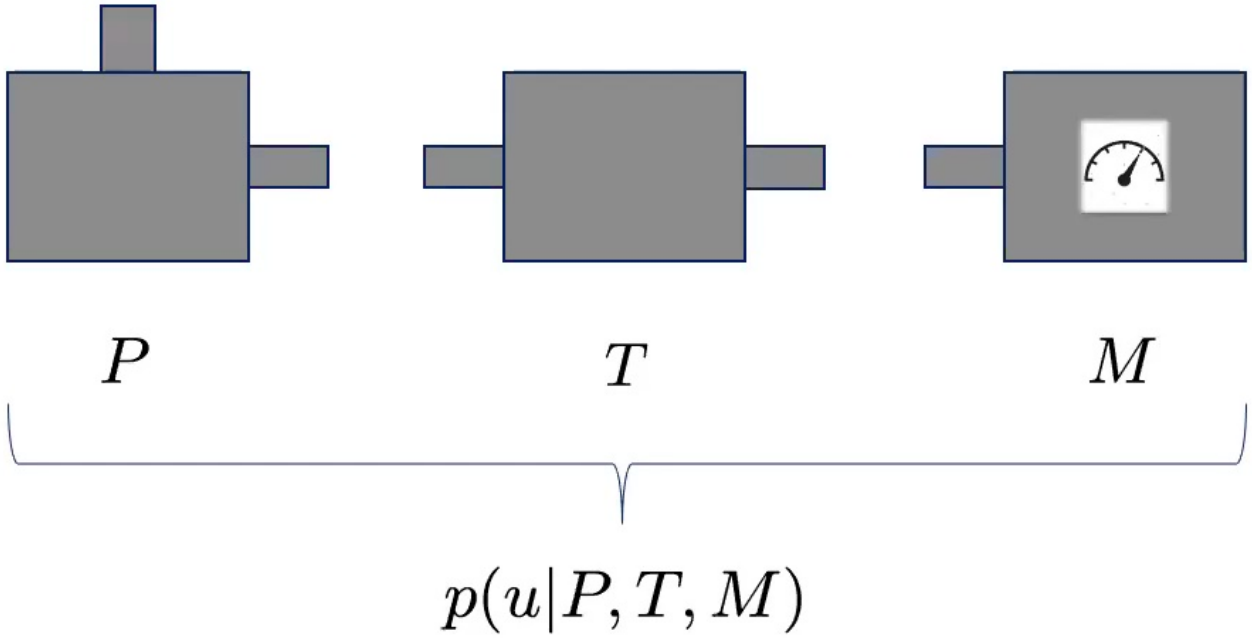
- Standard ontological models framework

- A new proposal

# Operational approach to physical theories

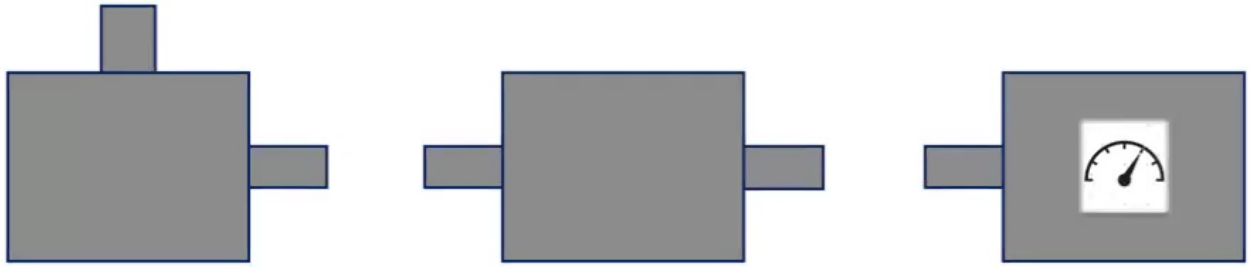
N. Harrigan, R.W. Spekkens, Found. of Phys. **40**, 2, 155-157 (2010)

- A *physical theory* is just a tool to predict the statistics of outcomes from experimental procedures.



## Standard ontological models framework

### Operational quantum theory



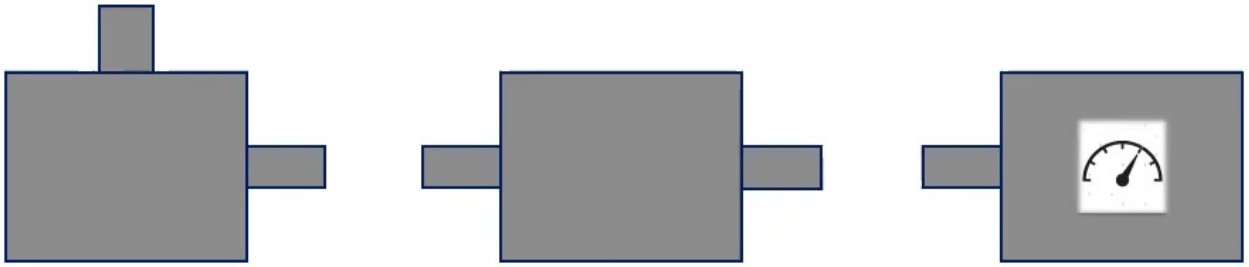
$P$ $T$ $M$

$\rho$ $\mathcal{E}$ $\{E_u\}$

(Density Operator) (CPTP Map) (POVM)

# Standard ontological models framework

## Operational quantum theory



$P$ $T$ $M$

$\rho$ $\mathcal{E}$ $\{E_u\}$

(Density Operator) (CPTP Map) (POVM)

$$p(u|P,T,M) = \mathrm{Tr}(\varepsilon(\rho)E_u)$$ (Born Rule)

## Standard ontological models framework

# Ontological model

- The system has definite properties even if no observer and no experiment.

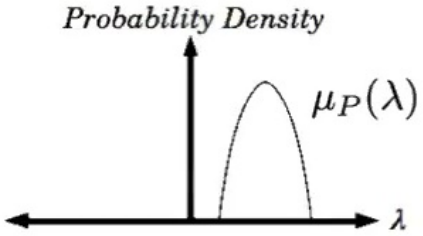
> These systems are presumed to have attributes regardless of whether they are being subjected to experimental test, and regardless of what anyone knows about them. These attributes describe the real state of affairs of the system. Thus a specification of which instance of each attribute applies at a given time we call the *ontic state* of the system.

R.W. Spekkens, Phys. Rev. A, **71**, 052108 (2005)

# Ontological model

- The system has definite properties even if no observer and no experiment.
- These are represented by the ontic states $\lambda \in \Lambda$.
- Experimental procedures:

$$P \longrightarrow \mu_P(\lambda)$$



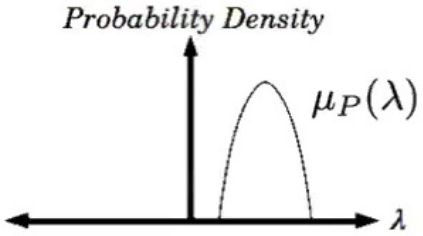
# Ontological model

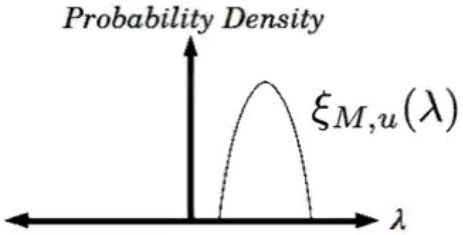
- The system has definite properties even if no observer and no experiment.
- These are represented by the ontic states $\lambda \in \Lambda$ .
- Experimental procedures:

$$P \longrightarrow \mu_P(\lambda)$$

$$T \longrightarrow \Gamma_T(\lambda, \lambda')$$

$$M, u \longrightarrow \xi_{M,u}(\lambda)$$



# Ontological model

- The system has definite properties even if no observer and no experiment.
- These are represented by the ontic states $\lambda \in \Lambda$ .
- Statistics (classical probability theory):

$$p(u|P,T,M) = \int d\lambda' d\lambda \, \xi_{M,u}(\lambda') \Gamma_T(\lambda', \lambda) \mu_P(\lambda)$$

## Standard ontological models framework

### Achievements

- Mathematizes a notion of reality.

- General and theory-independent.

## Standard ontological models framework

### Achievements

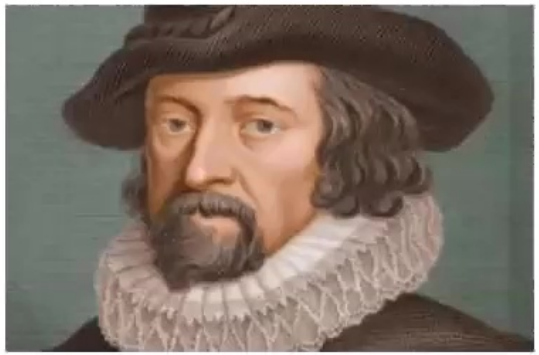
- Mathematizes a notion of reality.
- General and theory-independent.
- Allows to rigorously define departure from classical physics.

## Standard ontological models framework

What picture of the world an ontological model describes?

# Scientific revolution

Galileo Galilei (1564-1642)



Francis Bacon (1561-1626)

Isaac Newton (1642-1727)

# Scientific revolution

Galileo Galilei (1564-1642)

Francis Bacon (1561-1626)

Isaac Newton (1642-1727)

- Empiricism.
- Materialism.
- Mechanicism.

# Standard ontological models framework

## Scientific revolution

Galileo Galilei (1564-1642)

Francis Bacon (1561-1626)

Isaac Newton (1642-1727)

- Empiricism.
- Materialism.
- Mechanicism.
- Removal of subjectivity.

## Standard ontological models framework

Ontological models embrace scientific materialism

# Standard ontological models framework

Scientific materialism:

- Empiricism
- Materialism
- Mechanicism
- Removal of subjectivity

## Standard ontological models framework

Ontological models embrace scientific materialism

Is the latter the only way of having a notion of reality?

# Outline

- Standard ontological models framework

- A new proposal

## A new proposal

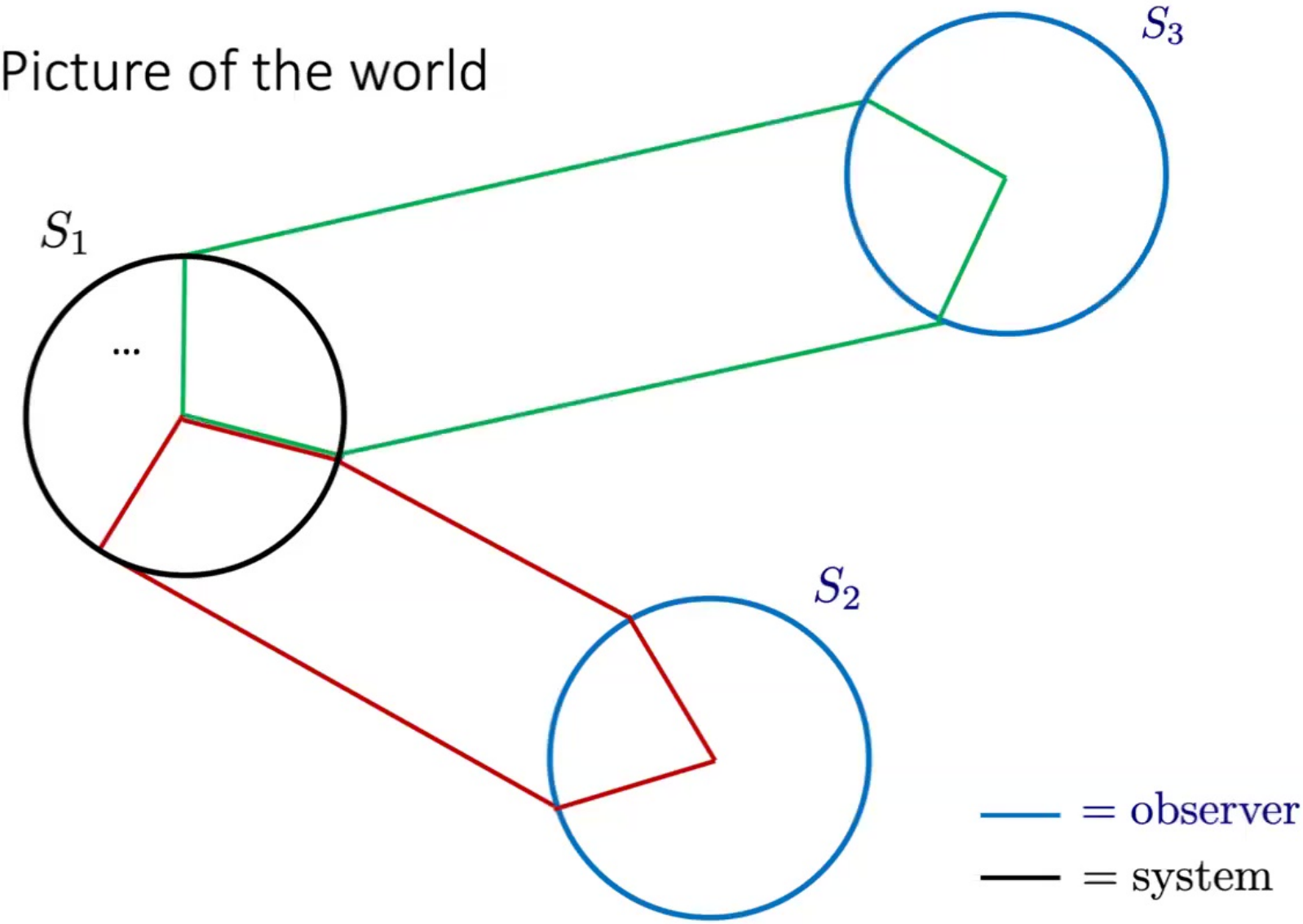
For something to exist is for something to be recorded.

## A new proposal

### Considerations

- Ontic states cannot be represented by points.
- Relational notion of reality.
- No special role of the subject.
- Interconnectedness.
- Physical theory as a theory of information.

# A new proposal



# A new proposal

| Framework | Reality |
| --- | --- |
| Ontological models | Stuff |
| Memory ontology | Processes |

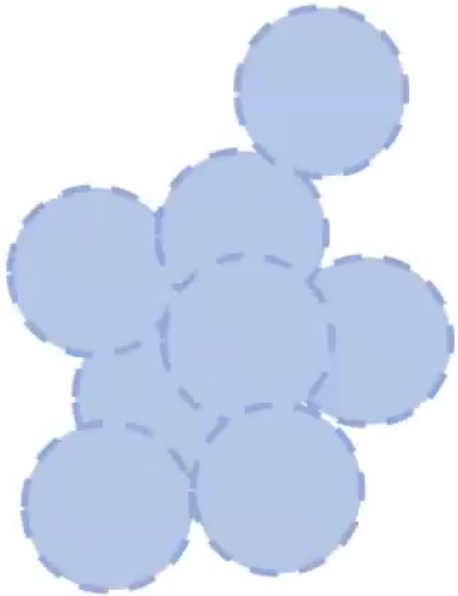
How to implement this new proposal into a rigorous theory-independent mathematical framework?

# A new proposal – mathematical framework

## Intuition

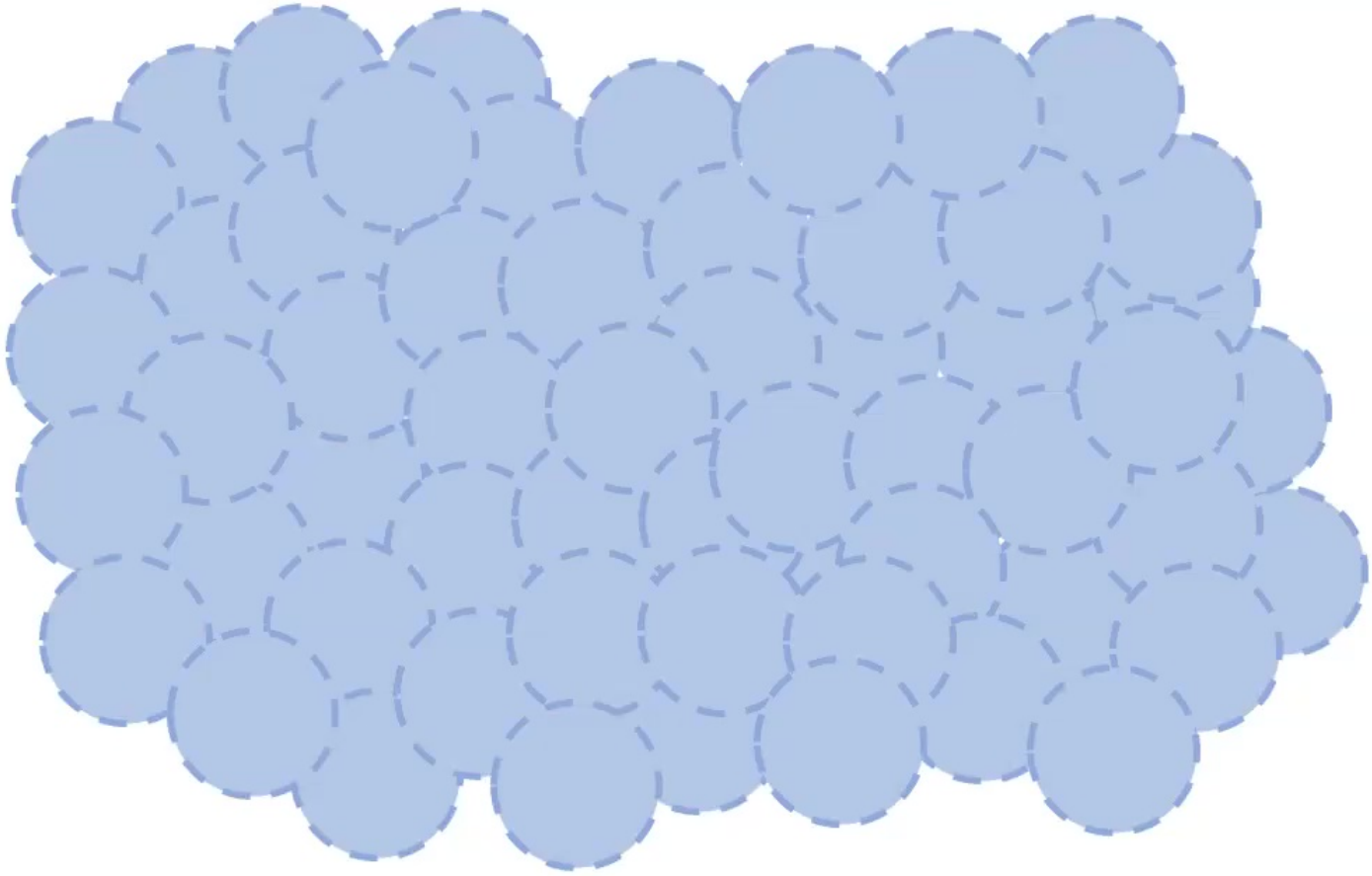
# A new proposal – mathematical framework

## Intuition



# A new proposal – mathematical framework

## Intuition



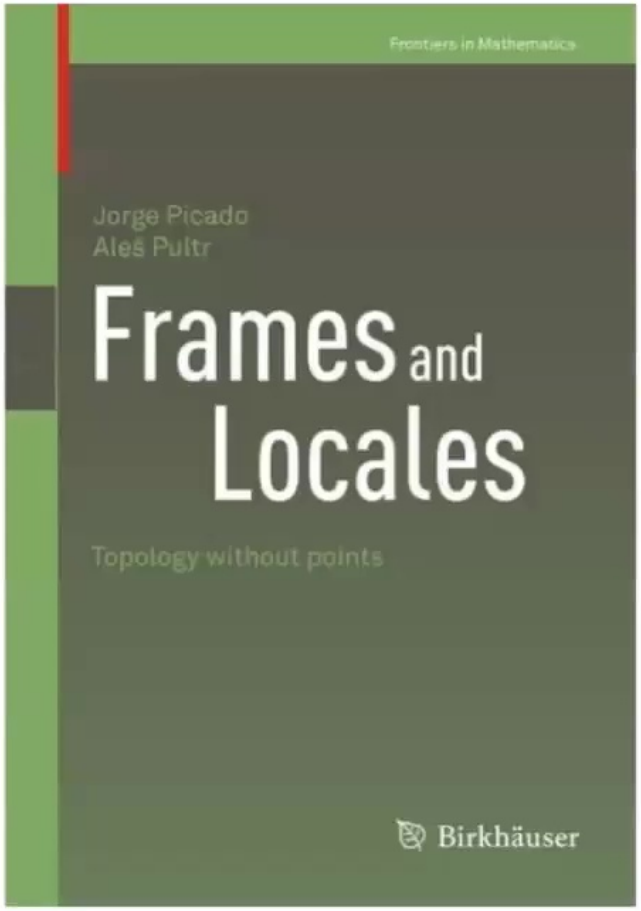
## Locales - definition

- A locale is a complete lattice $\mathcal{V}$ that satisfies the distributive law,

$$(\bigvee_{a \in A} a) \wedge b = \bigvee_{a \in A} \{a \wedge b \mid a \in A\} \quad \forall A \subseteq \mathcal{V}, b \in \mathcal{V}.$$

# A new proposal – mathematical framework

## Locales



## A new proposal – mathematical framework

### Possible implementation

- Ontic state of a system described by a spot in a locale (point-free topological space), $v \in \mathcal{V}$.

## Locales - example

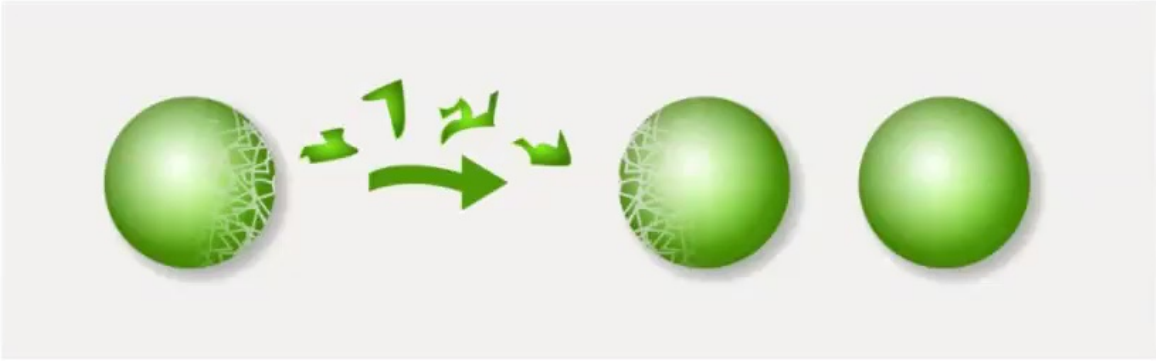
- The regular opens of $\mathbb{R}$, $\{u \in \Omega(\mathbb{R}) \mid u = Int(Cl(u))\}$.

# A new proposal – mathematical framework

## Locales – relevant feature

- In the theory of locales there are *more* subobjects than in standard point topology.

Math application: Solving Banach-Tarski paradox.



A. Simpson, Annals of Pure and Applied Logic 163, 1642–1659 (2012)

## Locales approach - comments

- Locales ⟶ **intuitionistic logic**.

- **Probability theory on locales** is missing.

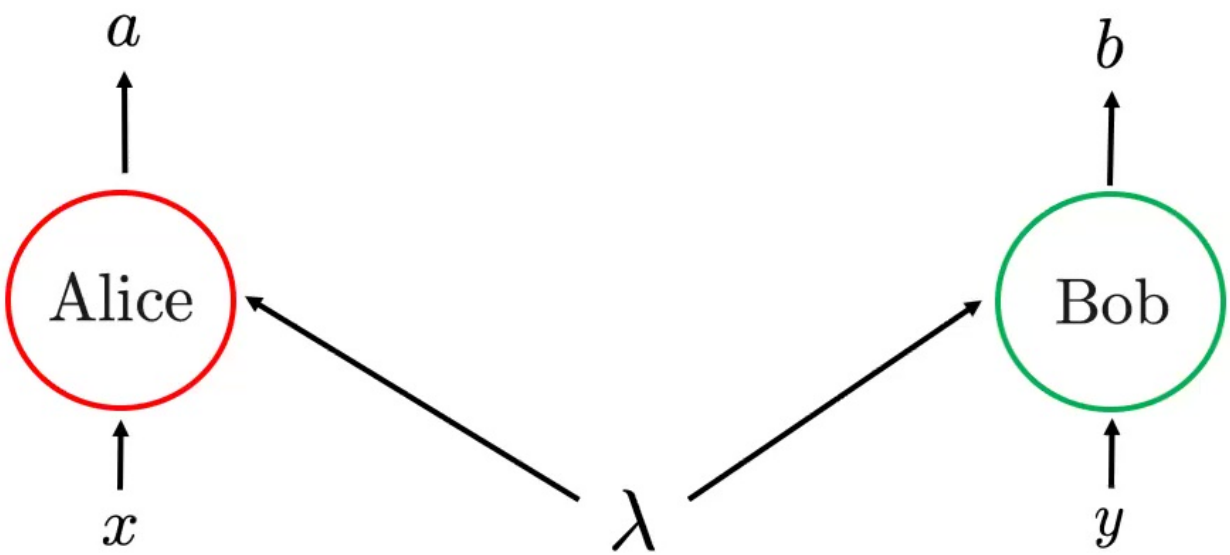
# A new proposal – mathematical framework

| Framework | Reality | Ontic states | Statistics |
|---|---|---|---|
| Ontological model's framework | Stuff | Points in measurable space | Classical probability theory |
| Memory ontology framework | Processes | Spots in locales | ? |

What about (no-)go theorems?

# A new proposal – Bell (no-)go theorem

## Bell's scenario




$$x, y, a, b \in \{0, 1\}$$

## A new proposal – Bell (no-)go theorem

### Bell's local causality

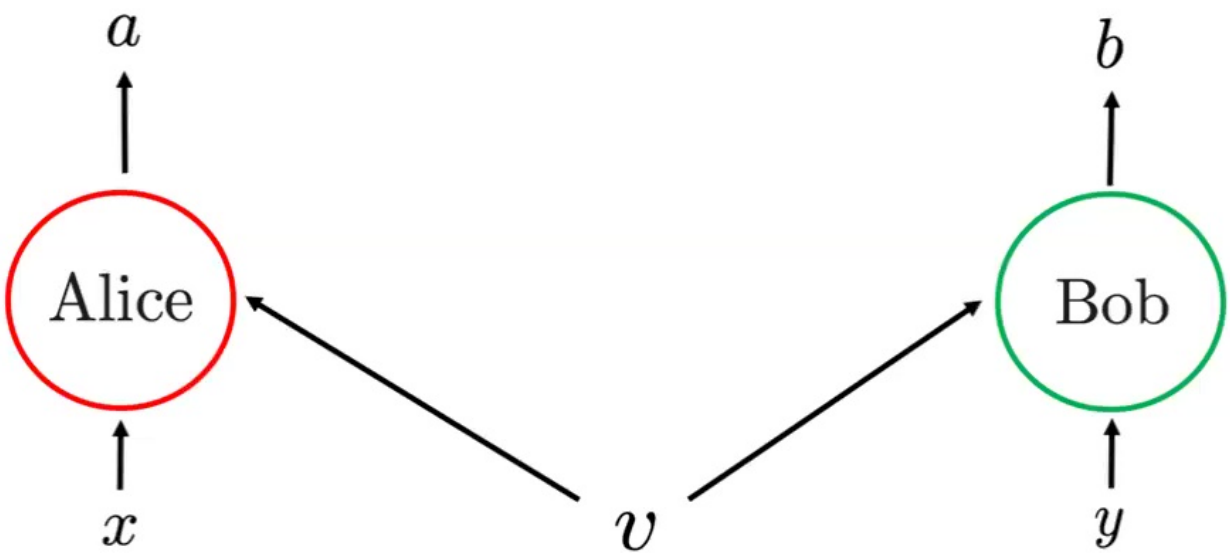
Bell's local causality ⟶ 1. Reichenbach principle of common cause

2. Relativistic causal structure

This implies factorability, $p(a, b|x, y, \lambda) = p(a|x, \lambda)p(b|y, \lambda)$,
which leads to Bell inequality. QT violates it.

# A new proposal – Bell (no-)go theorem

## Bell's scenario




$$x, y, a, b \in \{0, 1\}$$

## A new proposal – Bell (no-)go theorem

Change in probability theory – intuition

$$\overbrace{p(v)}^{\text{Spot}} \geq p(\overbrace{\bigcup_{u} u}^{v})$$

$$\underbrace{u}_{\text{Subspot}}$$

## A new proposal – Bell (no-)go theorem

$$p(a,b|x,y,v) \geq \underbrace{p(a,b|x,y,v)}$$

Local causality $\longrightarrow$ $||$

$$p(a|x,v)p(b|y,v)$$

CHSH expression has a higher upper bound

## A new proposal – Bell (no-)go theorem

$$p(a,b|x,y,v) \geq \underbrace{p(a,b|x,y,v)}$$

Local causality $\longrightarrow$ $||$

$$p(a|x,v)p(b|y,v)$$

CHSH expression has a higher upper bound

# What’s next?

## A new proposal – Bell (no-)go theorem

$$p(a,b|x,y,v) \geq \underbrace{p(a,b|x,y,v)}$$

Local causality $\longrightarrow$ $||$

$$p(a|x,v)p(b|y,v)$$

CHSH expression has a higher upper bound

# Open questions

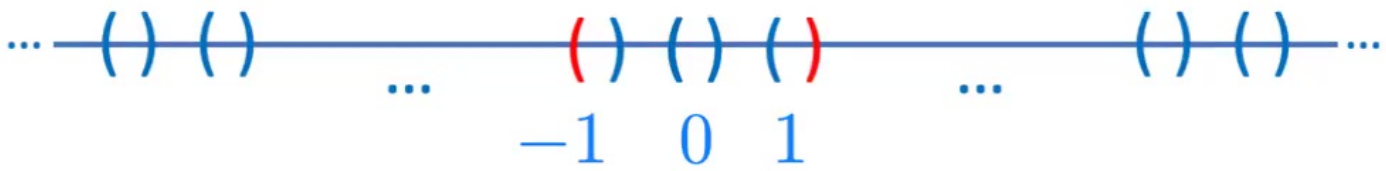
- Develop probability theory on locales.

- Possibilities other than locales to implement the new proposal?

# A new proposal – mathematical framework

## Locales - example

- The regular opens of $\mathbb{R}$, $\{u \in \Omega(\mathbb{R}) \mid u = Int(Cl(u))\}$.




$$(-1, 0) \vee (0, 1) = (-1, 1)$$