Title: Correlations all the way Down?

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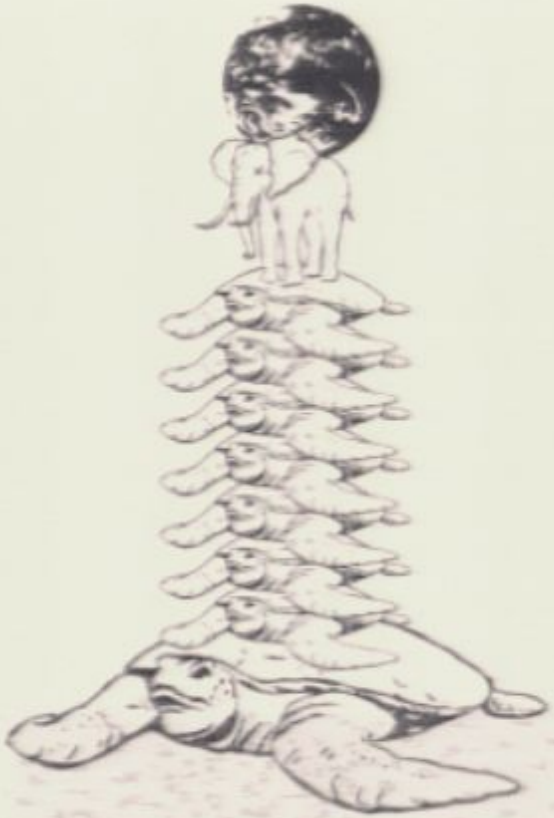
Abstract: I give a review and assessment of relational approaches to quantum theory – that is, approaches that view QM “as an account of the way distinct physical systems affect each other when they interact – and not the way physical systems ‘are’”. I argue that the “relational QM” is a misnomer: the correct way to understand these approaches is in terms of structuralism, whereby the correlations themselves are fundamental. I then argue that the connection to gravitational physics and gauge symmetries has a crucial impact on the attractiveness of such approaches.

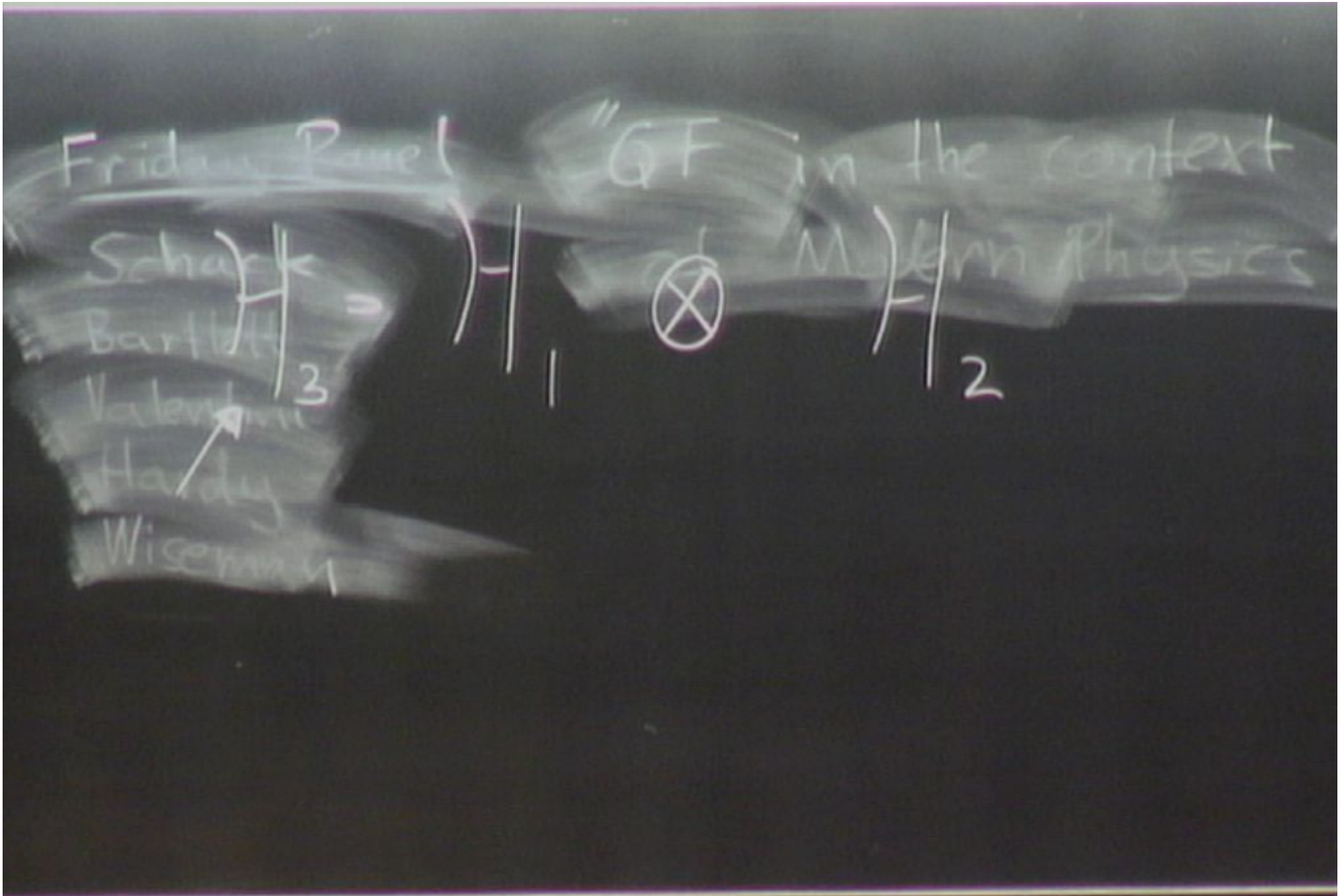


Correlations all the way down?

Dean Rickles

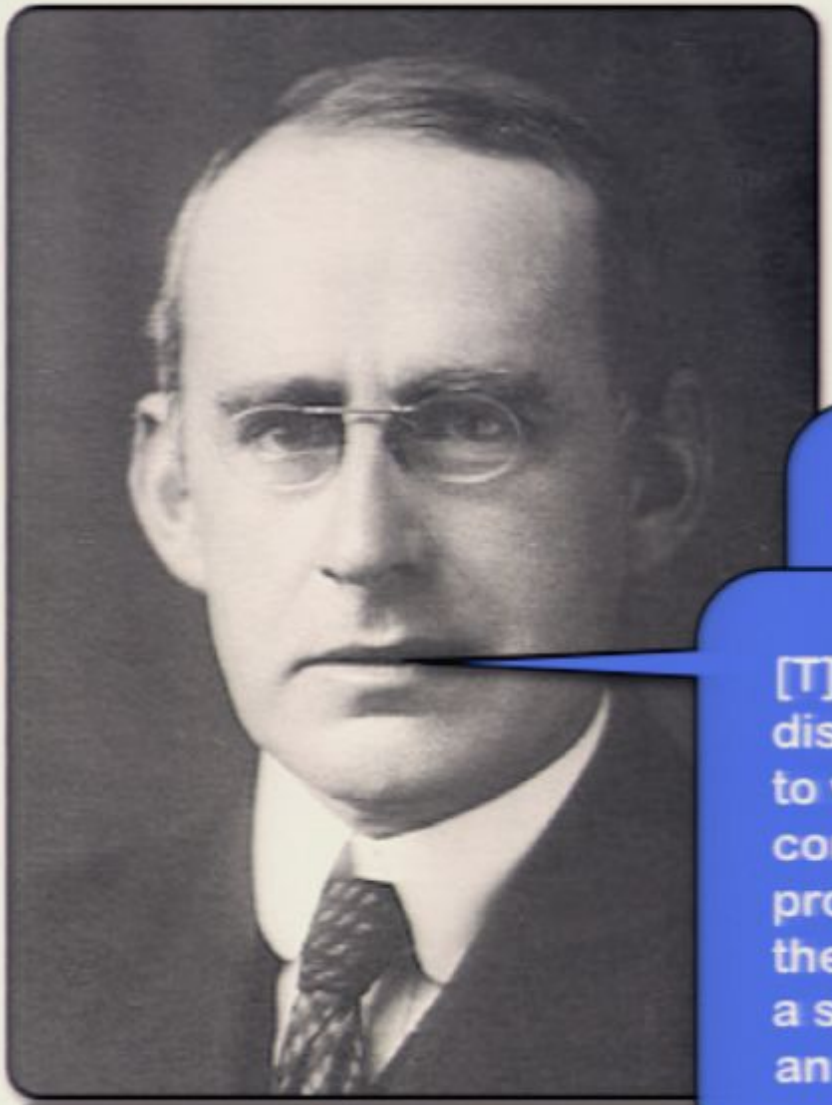
PI Griffith University The University of Queensland The University of Sydney

Australian Government
Australian Research Council


Fridrich Pauer "GF in the context
Schack
Bartlett
Valentini
Hardy
Wiseman
$\mathcal{H}_3 = \mathcal{H}_1 \otimes \mathcal{H}_2$
1
2

There are vectors in tensor product spaces that are not simple products of subsystem states

We have found that where science has progressed the farthest, the mind has but regained from nature that which the mind put into nature. We have found a strange footprint on the shores of the unknown. We have devised profound theories, one after another, to account for its origins. At last, we have succeeded in reconstructing the creature that made the footprint. And lo! It is our own.



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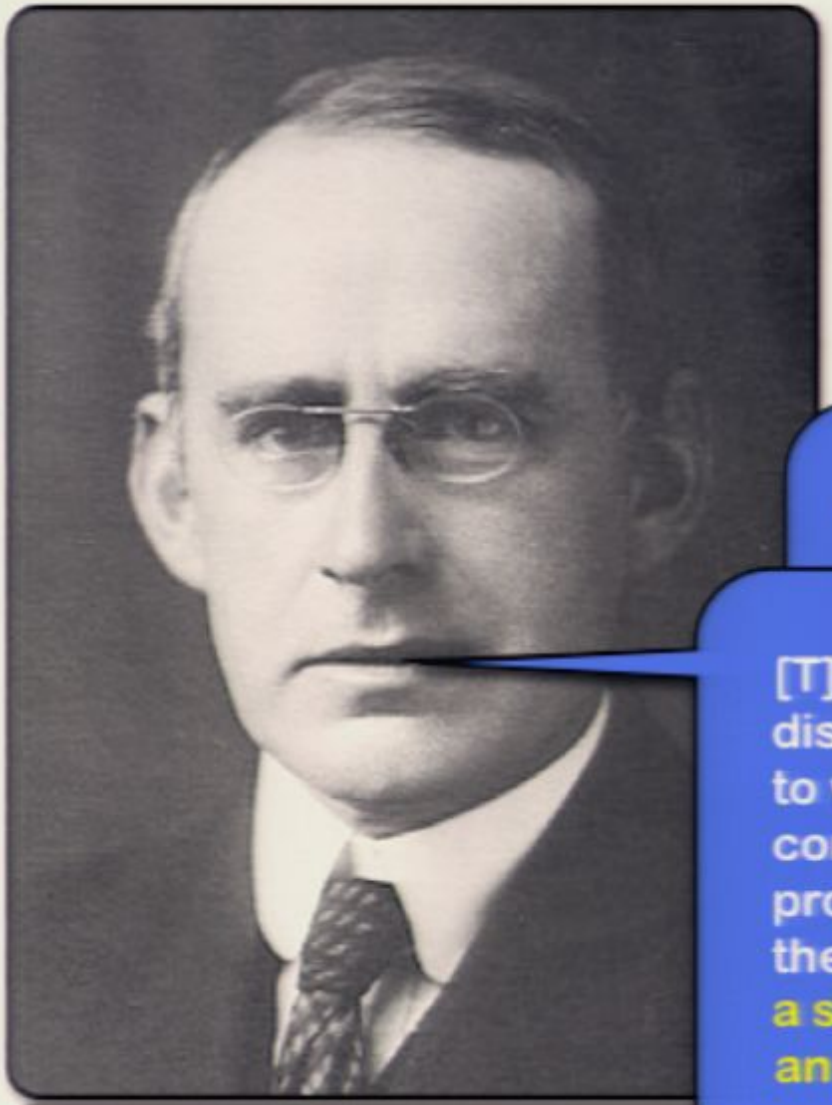
but

[T]he significance of a part cannot be dissociated from the system of analysis to which it belongs. As a structural concept the part is a symbol having no properties except as a constituent of the group-structure of a set of parts ... a structure does not necessarily imply an X of which it is the structure.



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Whitehead offers us an ontology of "events" as the real termini of our experiences in sense-awareness. Each event is an "actual entity" which is a concresence of prehensions of all previous events. In a "prehension" the prehending event brings within itself with a certain determinate "subjective form" the prehended event as an objective datum entering into the process that makes up the life of the prehending event. In this process the prehending event "becomes" while the prehended event achieves "objective immortality" and "perishes." There is no hylomorphic structure to the actual entities of this ontology; there is not "something that endures," material substance, and something which the enduring thing "has," properties, that can change. What is, is events, and events do not endure, they happen. In a prehension an event reaches out to "feel" other events; thus an actual entity "acts." Activity, not endurance, is the basic ontological status of entities in the philosophy of organism.

The fallacy of misplaced concreteness

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The first alternative is to assume that quantum mechanics refrains from making any definite statements about 'physical reality' just as relativity theory has taught us to refrain from defining 'absolute rest'. Rather QM only furnishes us with correlations between subsequent observations and these correlations are, in general, only statistical. The second alternative is to say that the wave function, or more generally the state vector, is a description of the physical reality. In that case one has to admit that the state vector may change in two fundamentally different ways: continuously and causally, as a result of the lapse of time, according to the time-dependent Schrodinger equation, and discontinuously and erratically, as a result of observations." [Wigner, Jauch, and Yanase, Some Comments Concerning Measurements in QM]

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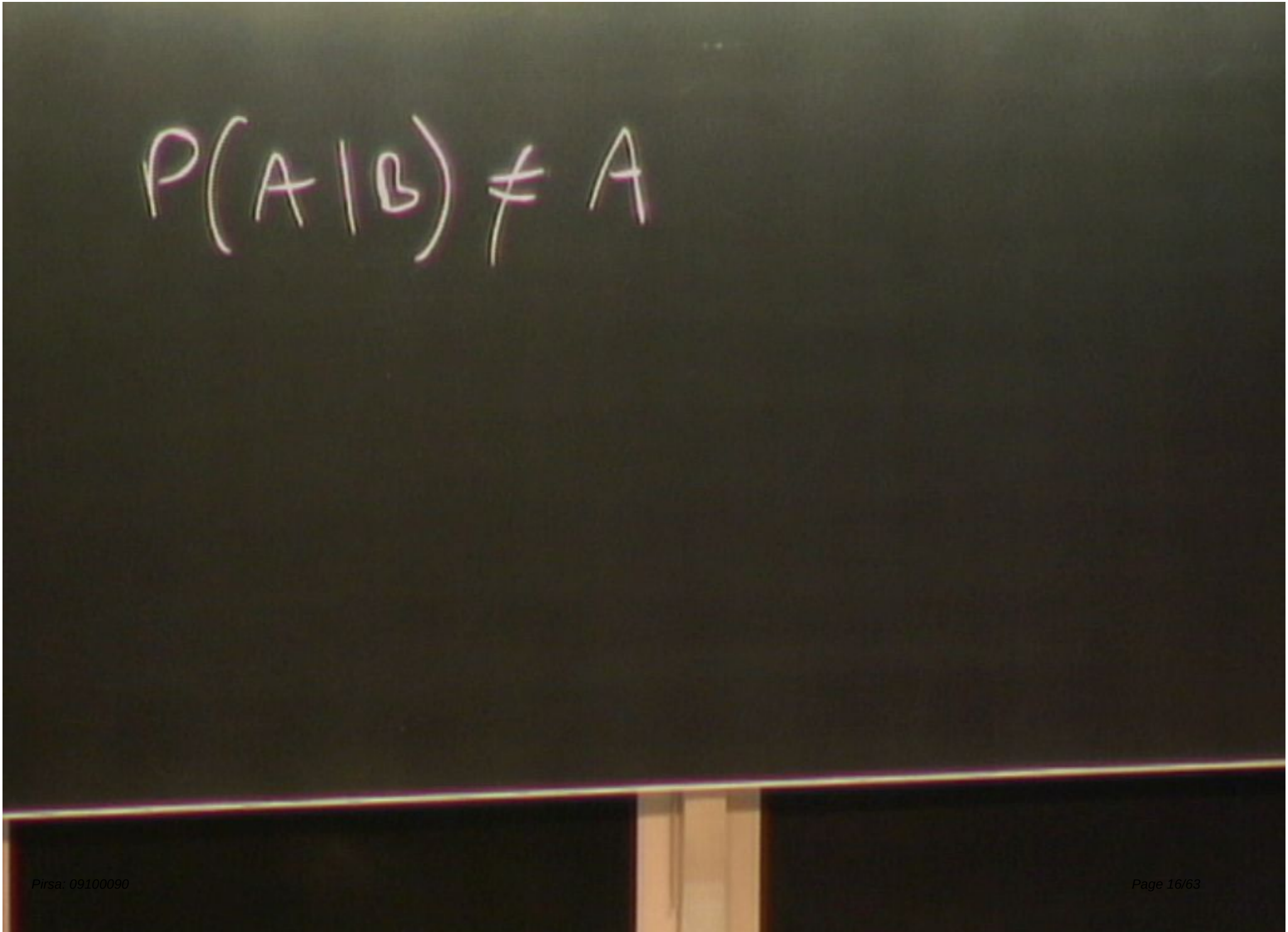
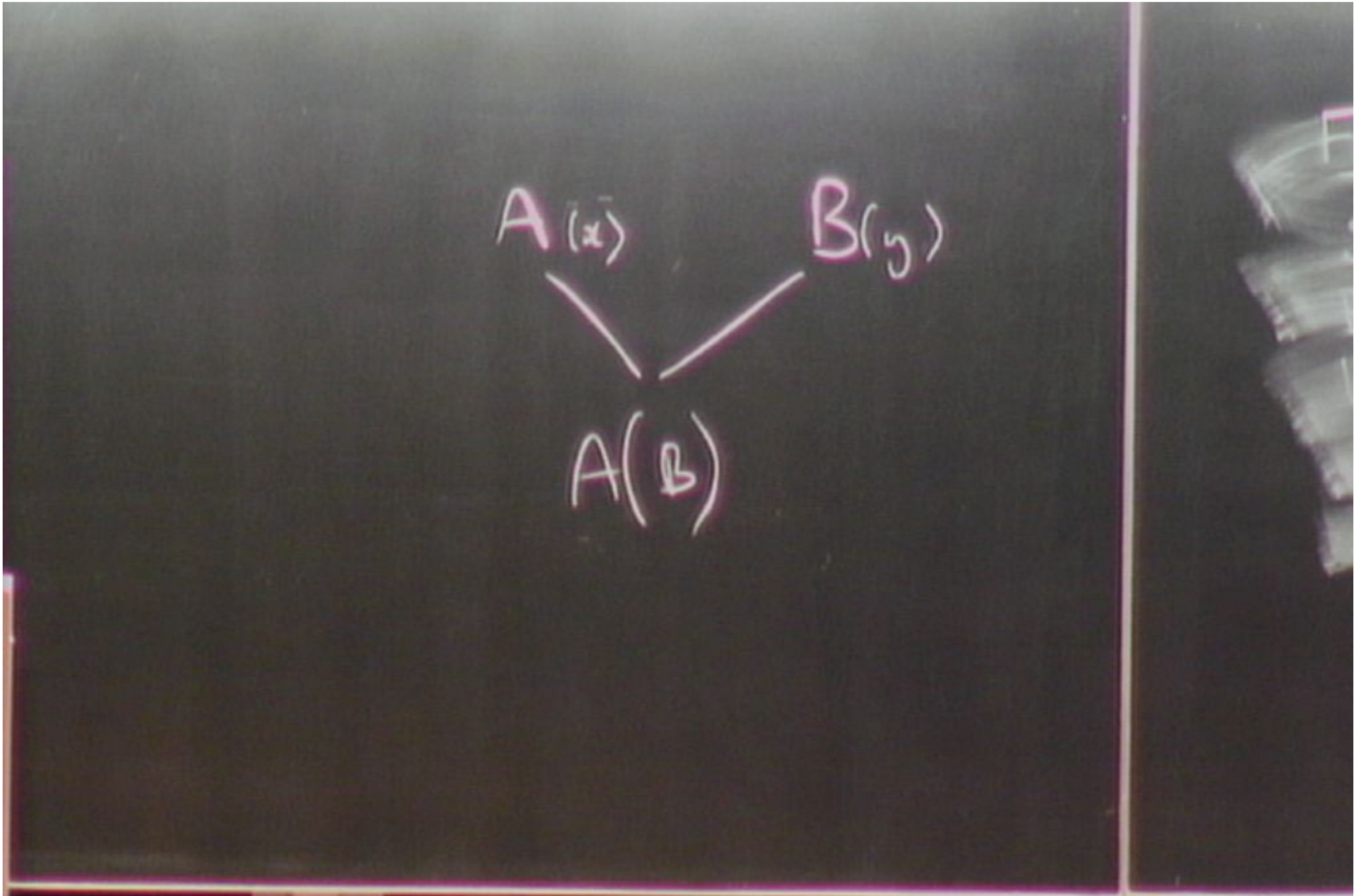
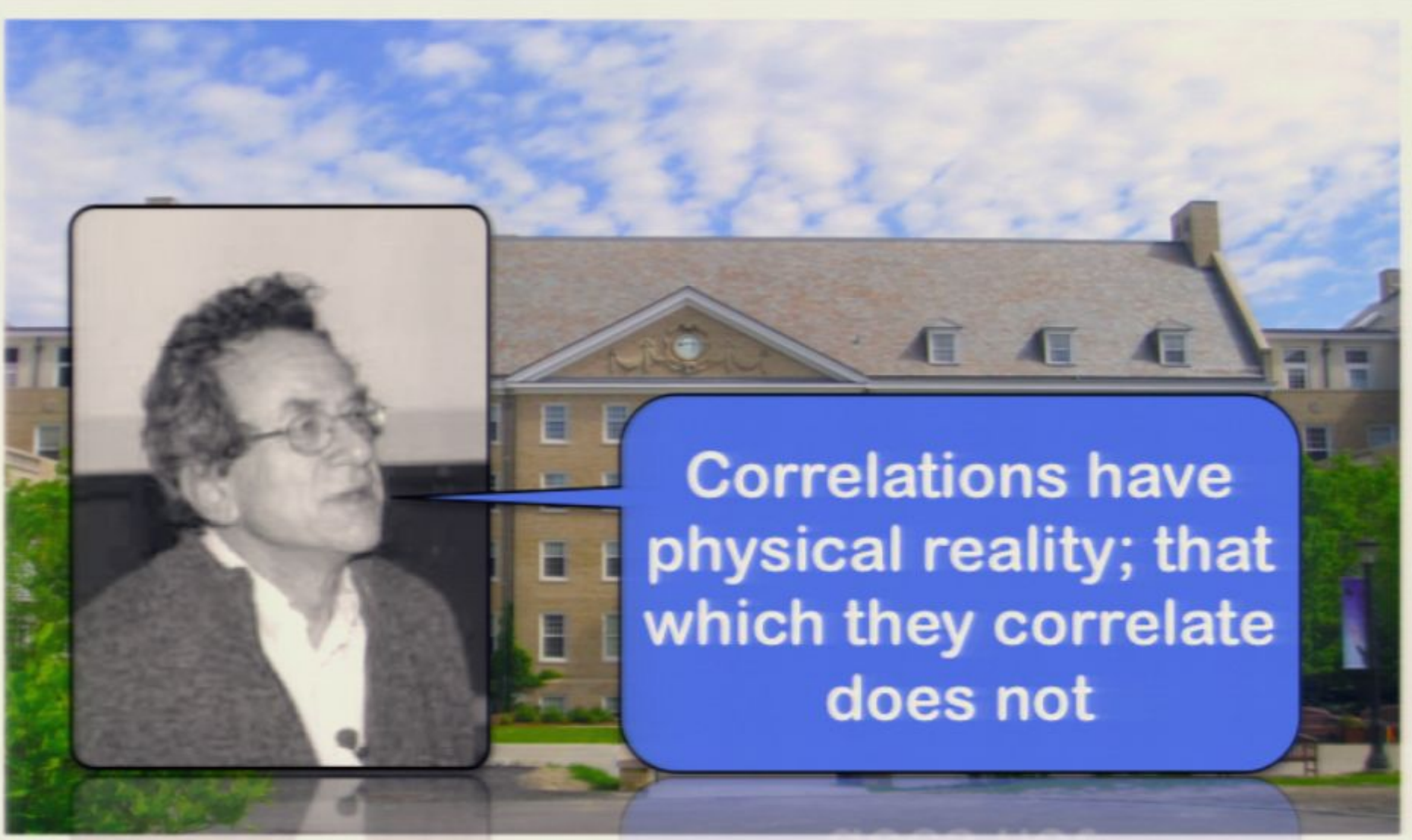

P(A|B) ≠ A


A(x̄)
B(y)
A(B)

According to the IIQM the only proper subjects for the physics of a system are its **correlations**



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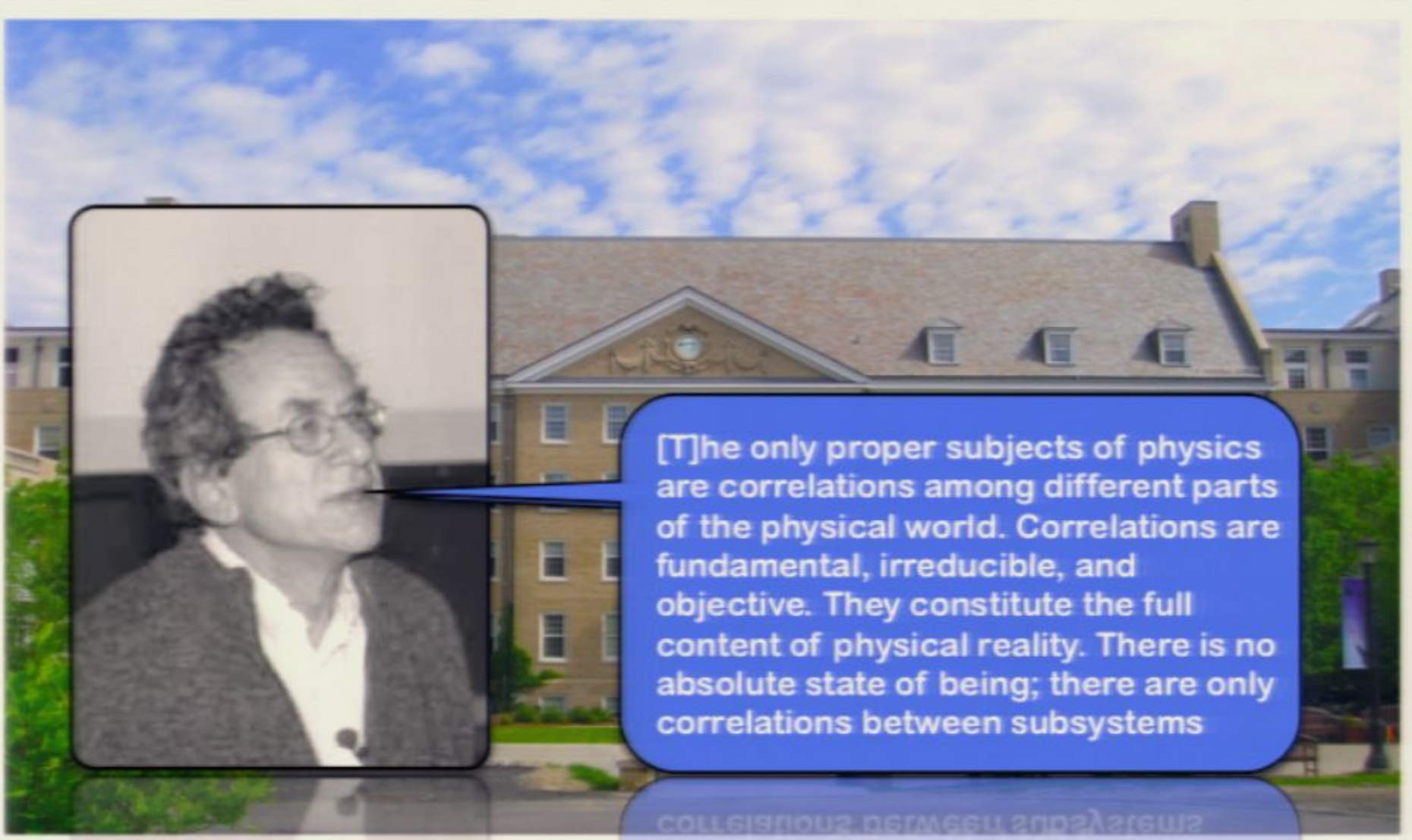

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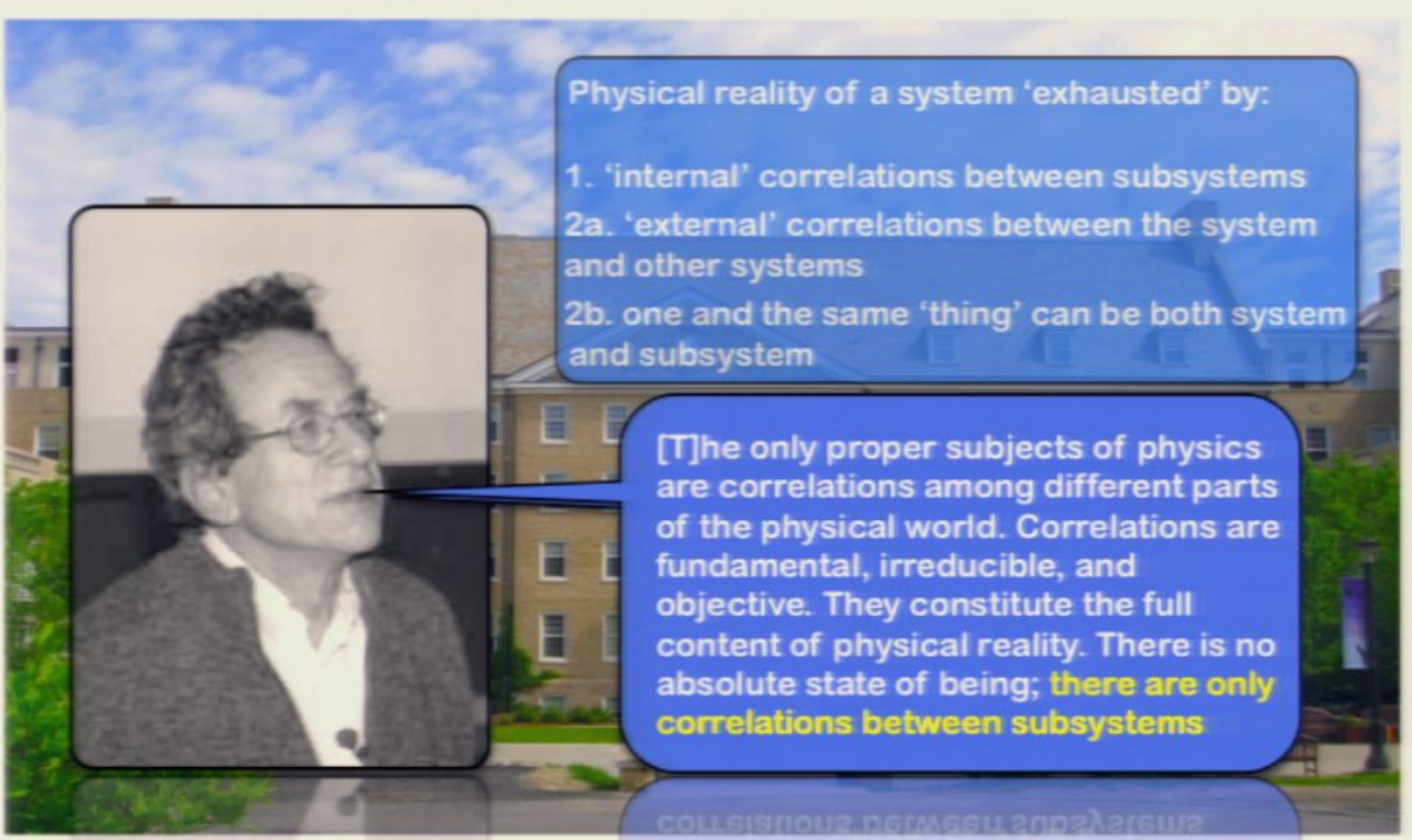


According to the IIQM the only proper subjects for the physics of a system are its **correlations**

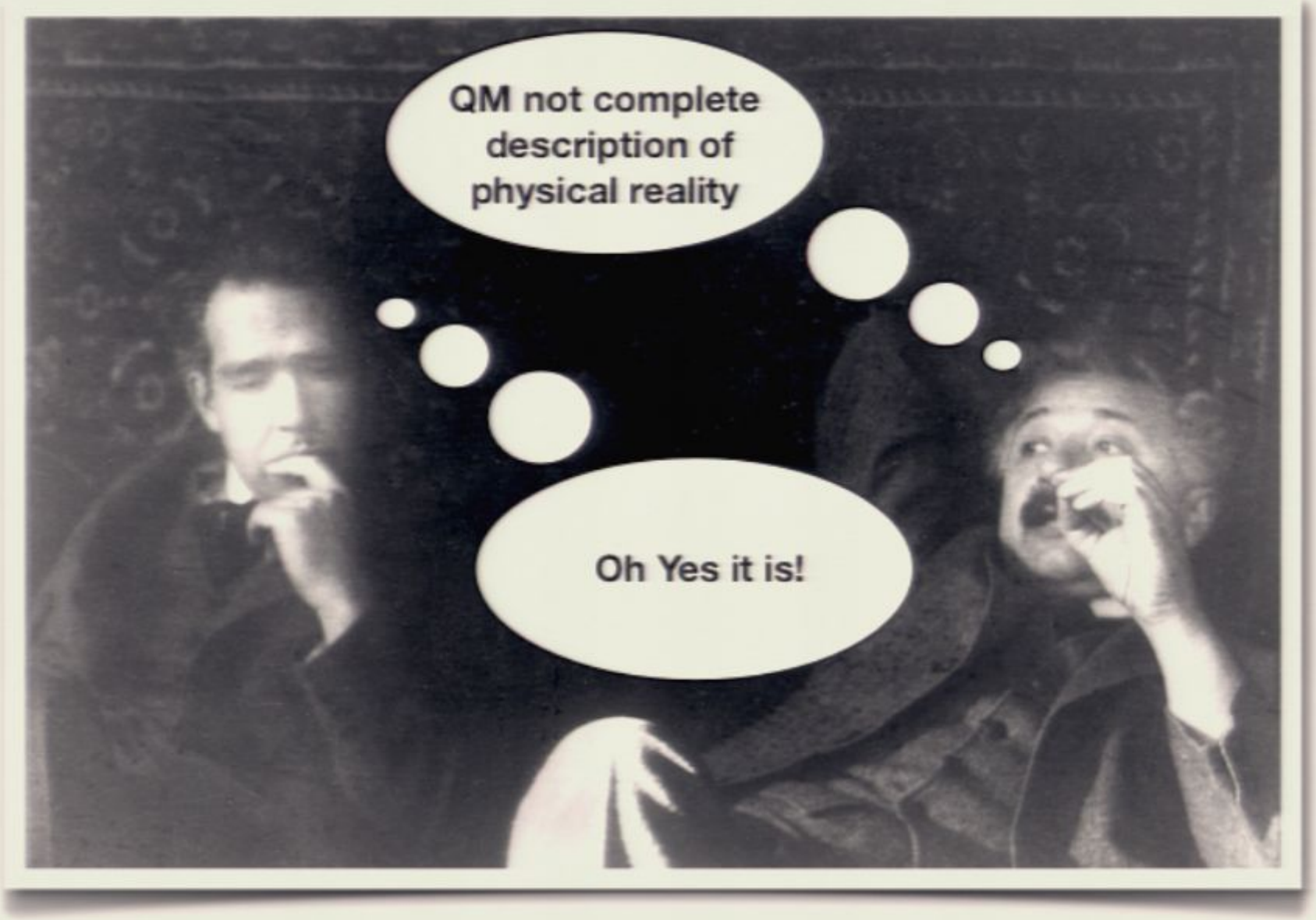
Subsystem density matrices as objective characterisation of their internal properties

Physical reality of a system 'exhausted' by:

1. 'internal' correlations between subsystems
2a. 'external' correlations between the system and other systems
2b. one and the same 'thing' can be both system and subsystem

[T]he only proper subjects of physics are correlations among different parts of the physical world. Correlations are fundamental, irreducible, and objective. They constitute the full content of physical reality. There is no absolute state of being; **there are only correlations between subsystems**

According to the IIQM the only proper subjects for the physics of a system are its **correlations**


QM not complete description of physical reality
Oh Yes it is!


QM not complete description of physical reality
Oh Yes it is!
'ish'

Critik

der

reinen Vernunft

von

Immanuel Kant,

Professor in Königsberg,

der Königl. Academie der Wissenschaften in Berlin

Mitglied.

Neueste Auflage.

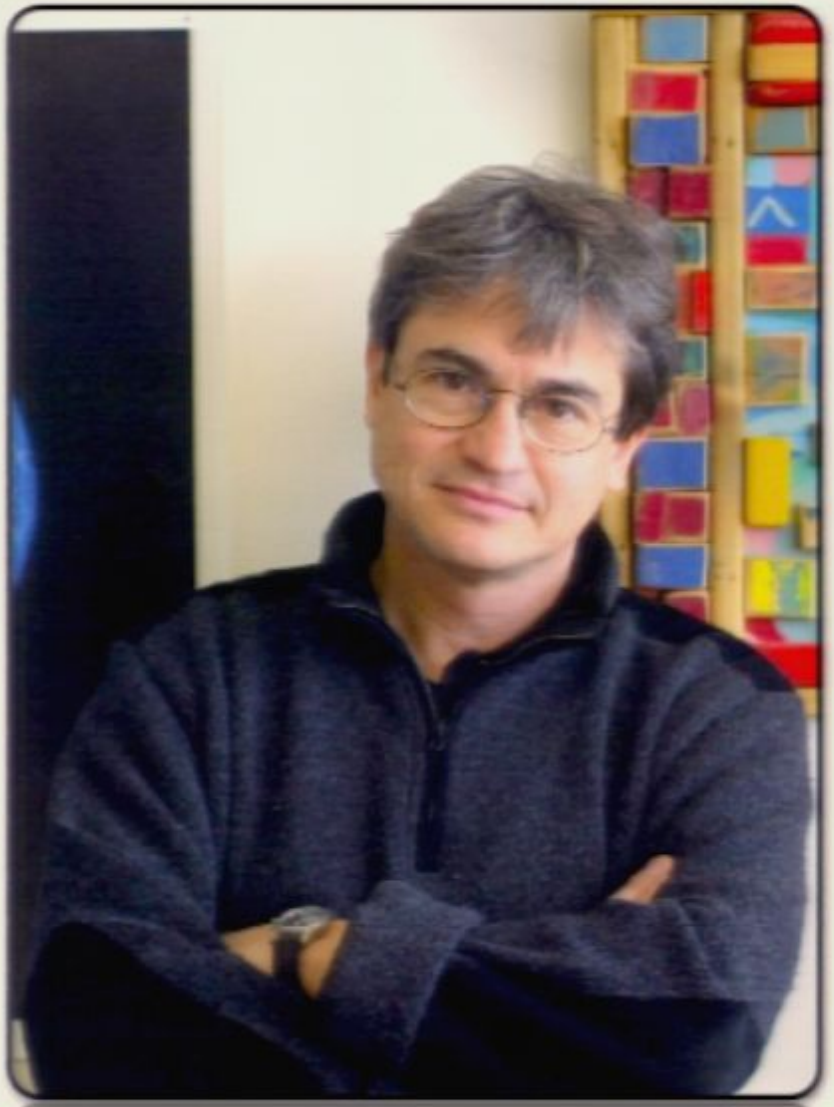
Frankfurt und Leipzig

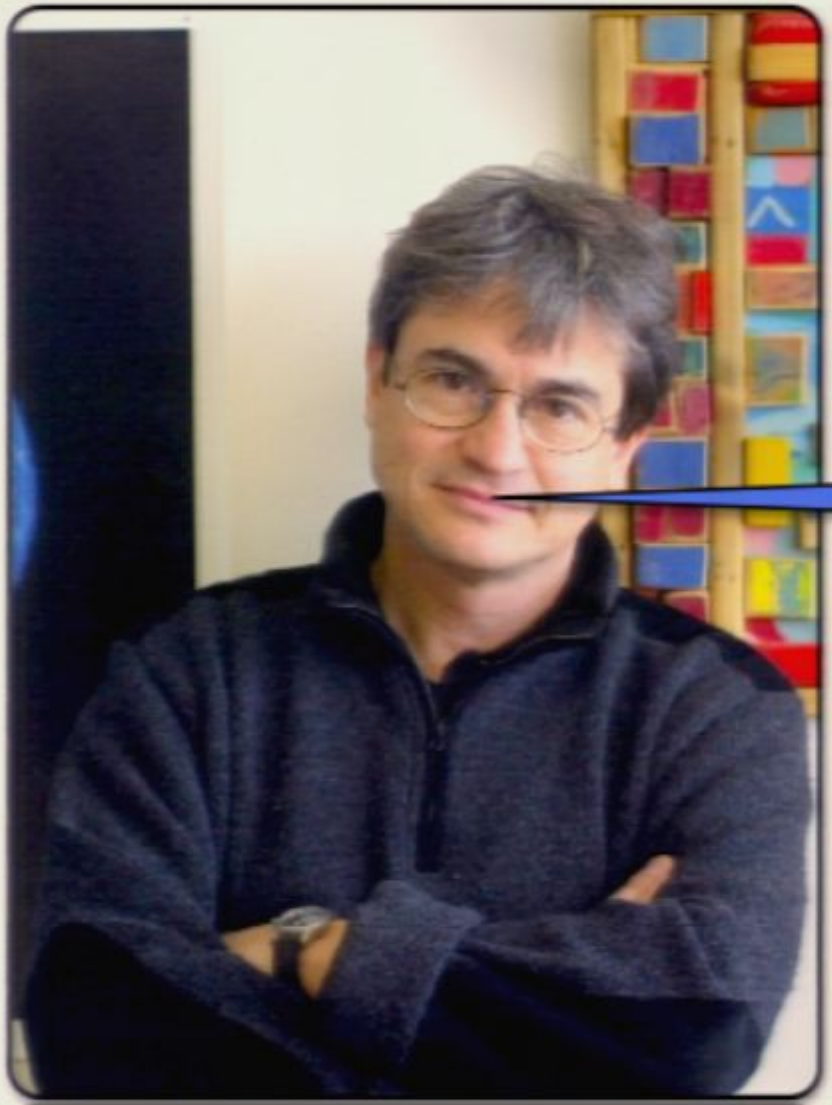
1794.

The actual specific values of the correlated quantities in the actual specific world we know, are beyond the powers of physics to articulate

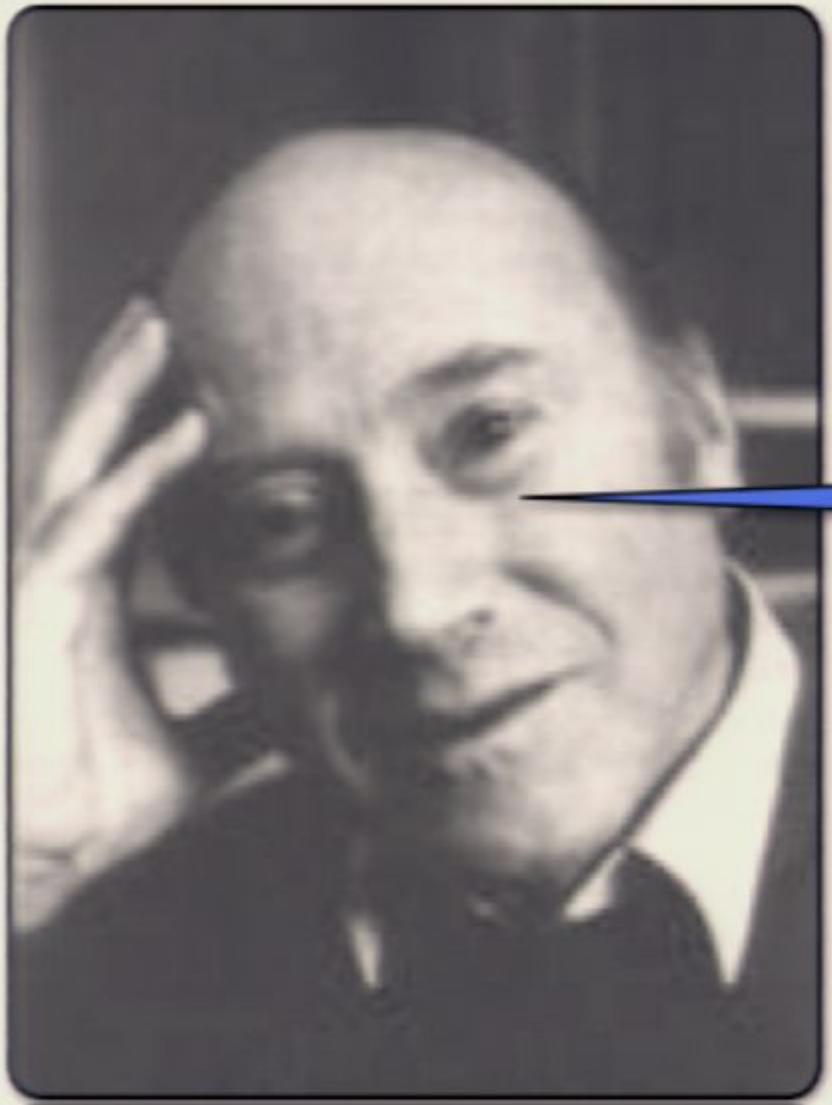
In our description of nature the purpose is not to disclose the real essence of the phenomena

Mermin, Critik ber Reinen Dinge

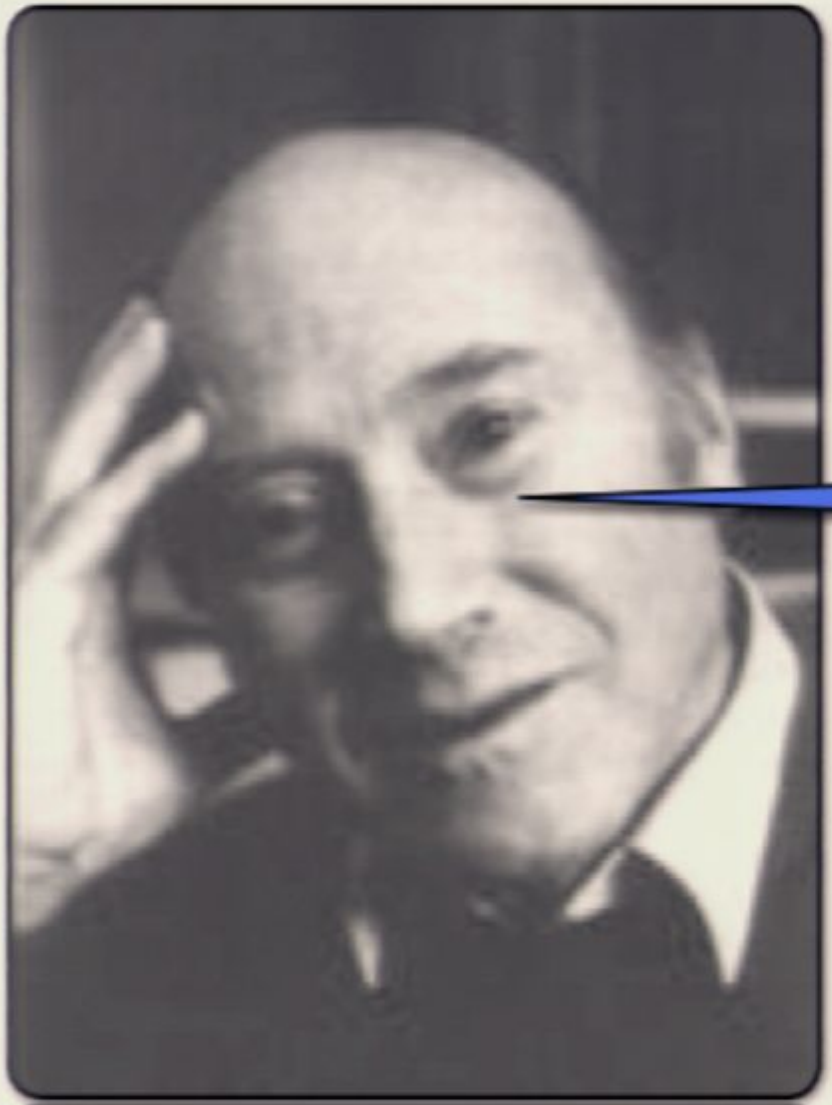




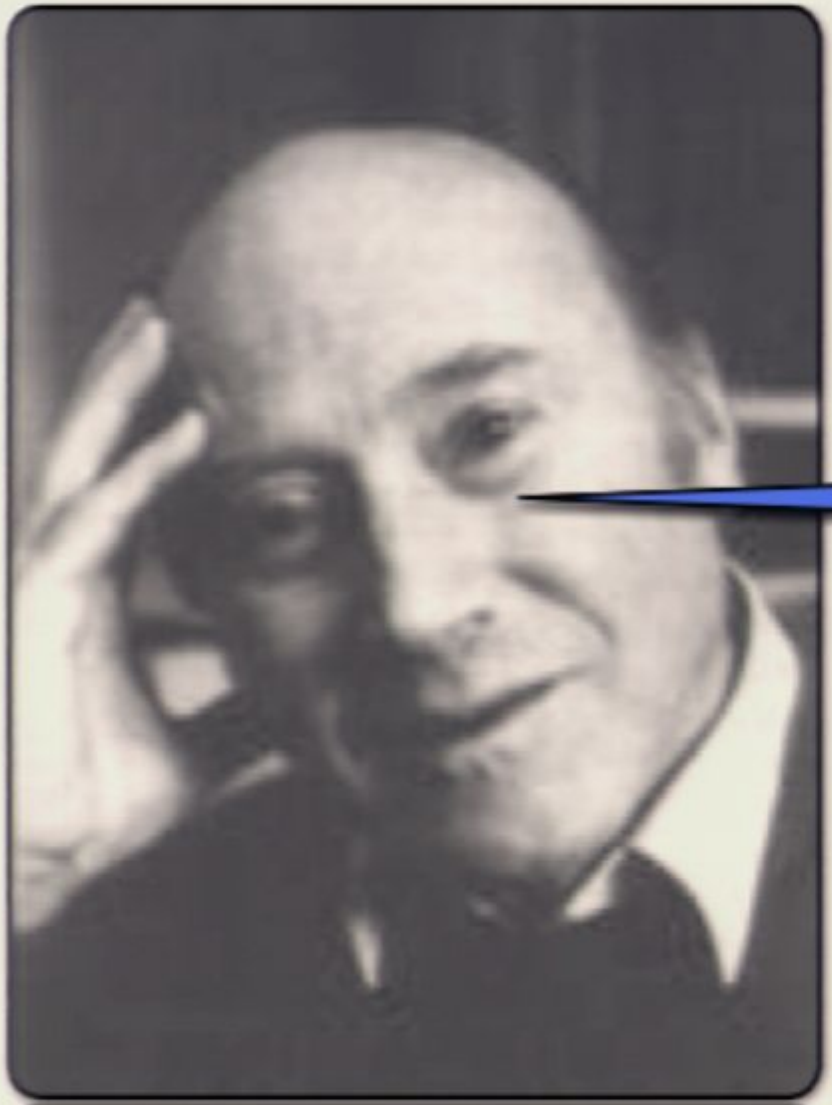
Physics is concerned with relations between physical systems. In particular, it is concerned with the description that physical systems give of other physical systems



An ‘event’ is regarded as the realization of an individual fact (and thus an ‘element of reality’ whereas a ‘state’ subsumes the probability assignment for the realization of a pattern of future events. It is not an element of reality.



The perseverance of the correlations between events over large distances is in itself no paradox. What appears paradoxical and differs from the case of classical correlations is only that the correlations are of such a nature that they cannot be attributed to correlations between assumed 'states of subsystems' but only as correlations between the events themselves. This corresponds in our picture to the statement that unaccomplished (potential) links belong to the realm of possibilities, not facts. They have neither a well defined individuality nor any independent localization properties



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An atomic fact is a combination of objects (entities, things) [and] it is essential to a thing that it can be a constituent part of an atomic fact
[TLP: 2.01-2.011]

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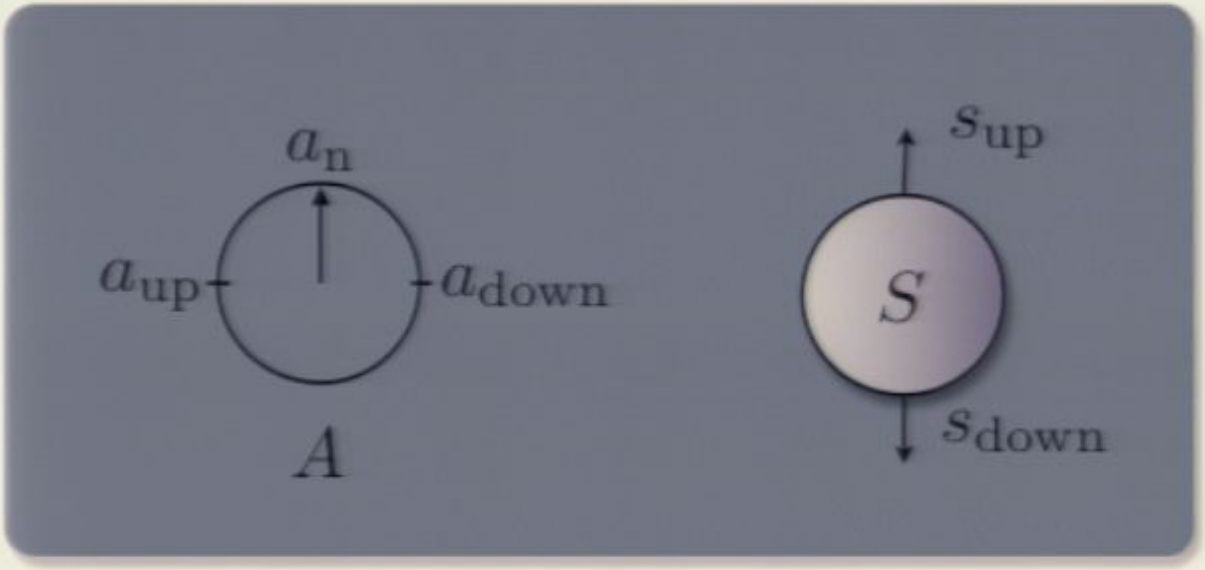
If true: then what **are** the systems (if not clusters of properties)?

Properties of quantum systems have no absolute meaning. Rather, they must be always characterised with respect to other physical systems

Correlations between the properties of quantum systems are more basic than the properties themselves

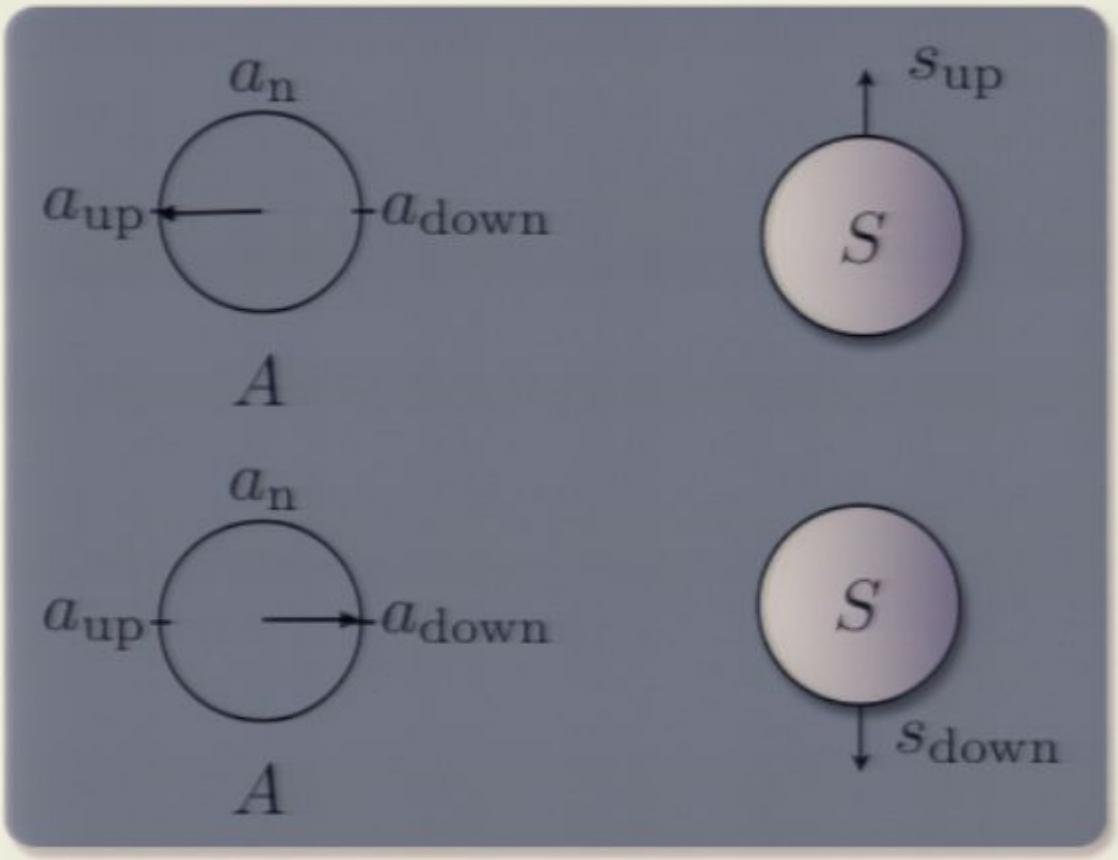
$$|I\rangle = |s_i\rangle \otimes |a_n\rangle \overset{U_H(t)}{\rightarrow} |s_i\rangle \otimes |a_i\rangle = |F\rangle$$



$$|s\rangle = \Sigma \alpha_i |s_i\rangle$$

$$(|s\rangle = \Sigma \alpha_i |s_i\rangle) \supset (|F\rangle = \Sigma \alpha_i |s_i\rangle \otimes |a_i\rangle)$$

$$\mathrm{Cor}(A,S) := p(a_i, s_j) = |\alpha_j|^2 \delta_{ij}$$



$$= \langle \underbrace{\Sigma \alpha_i |s_i\rangle \otimes |a_i\rangle}_{|F\rangle} | \underbrace{s_i\rangle\langle s_i}_{P_{s_i}} | \underbrace{a_i\rangle\langle a_i}_{P_{a_i}} | \underbrace{\Sigma \alpha_i |s_i\rangle \otimes |a_i\rangle}_{|F\rangle}$$

$$p(a_{up}, s_{down}) = 0 = p(a_{down}, s_{up})$$

(Altered) Relative States

- Correlations as the real thing
- Meaning of the singlet quantum state:
  - if an electron is spin up (down) then (necessarily) the apparatus will register 'spin up (down)'
  - Not about results of measurements of composite electron+apparatus
  - The electron's |up> is a relative state of the apparatus' |'up'>, in general:

$$|\psi\rangle = \sum_{i=1}^{n}\sum_{j=1}^{n} \psi_{ij}|A_i\rangle|B_j\rangle$$

Many Decompositions

$$|\psi\rangle = \frac{1}{\sqrt{2}}\Big(\underset{+\frac{1}{2}\hbar}{|\uparrow\rangle}\underset{-\frac{1}{2}\hbar}{|\downarrow\rangle} - \underset{-\frac{1}{2}\hbar}{|\downarrow\rangle}\underset{+\frac{1}{2}\hbar}{|\uparrow\rangle}\Big) \qquad \begin{matrix}\begin{pmatrix}1\\0\end{pmatrix}\begin{pmatrix}0\\1\end{pmatrix} & \begin{pmatrix}0\\1\end{pmatrix}\begin{pmatrix}1\\0\end{pmatrix}\\ +\frac{1}{2}\hbar\ -\frac{1}{2}\hbar & -\frac{1}{2}\hbar\ +\frac{1}{2}\hbar\end{matrix} = S_z = \frac{\hbar}{2}\begin{pmatrix}1 & 0\\ 0 & -1\end{pmatrix}$$

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$$|\psi\rangle = \frac{1}{\sqrt{2}}(|\uparrow\rangle|\downarrow\rangle - |\downarrow\rangle|\uparrow\rangle)$$

$$\begin{matrix} \begin{pmatrix}1\\0\end{pmatrix} & \begin{pmatrix}0\\1\end{pmatrix} & \begin{pmatrix}0\\1\end{pmatrix} & \begin{pmatrix}1\\0\end{pmatrix} \\ +\frac{1}{2}\hbar & -\frac{1}{2}\hbar & -\frac{1}{2}\hbar & +\frac{1}{2}\hbar \end{matrix} = S_z = \frac{\hbar}{2}\begin{pmatrix}1 & 0\\ 0 & -1\end{pmatrix}$$

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|\leftarrow\rangle|\rightarrow\rangle - |\rightarrow\rangle|\leftarrow\rangle)$$

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Not the same

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Equal

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Identical on the correlation view!

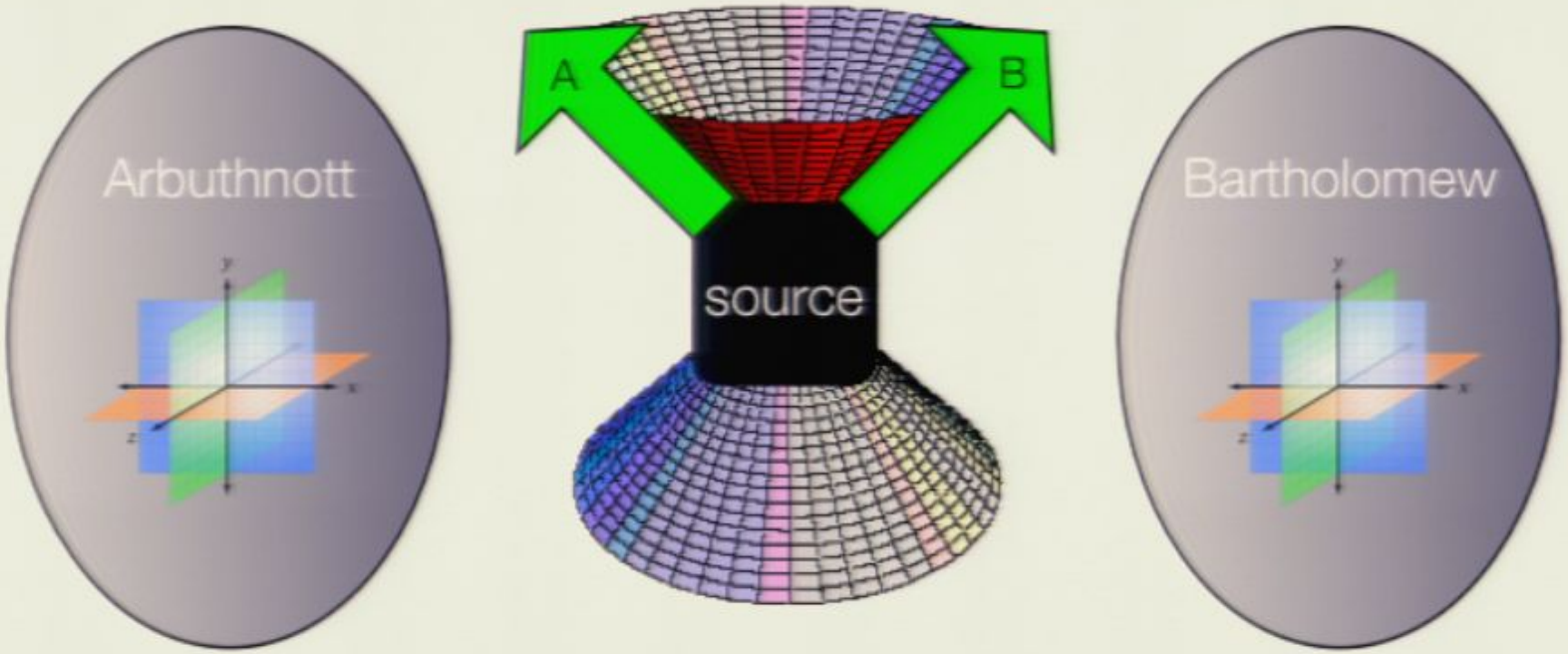
No-Go Results

Cabello shows that the 3 defining assumptions of IIQM cannot stand together:

- Density matrices describe all internal correlations of an isolated individual quantum system
- All correlations between subsystems of an isolated composite system are real objective internal properties of such subsystems
- Real objective internal properties of an isolated system must be local ("can't be altered by faraway events")

Also: no predefined local correlations

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|\uparrow\rangle|\downarrow\rangle - |\downarrow\rangle|\uparrow\rangle)$$



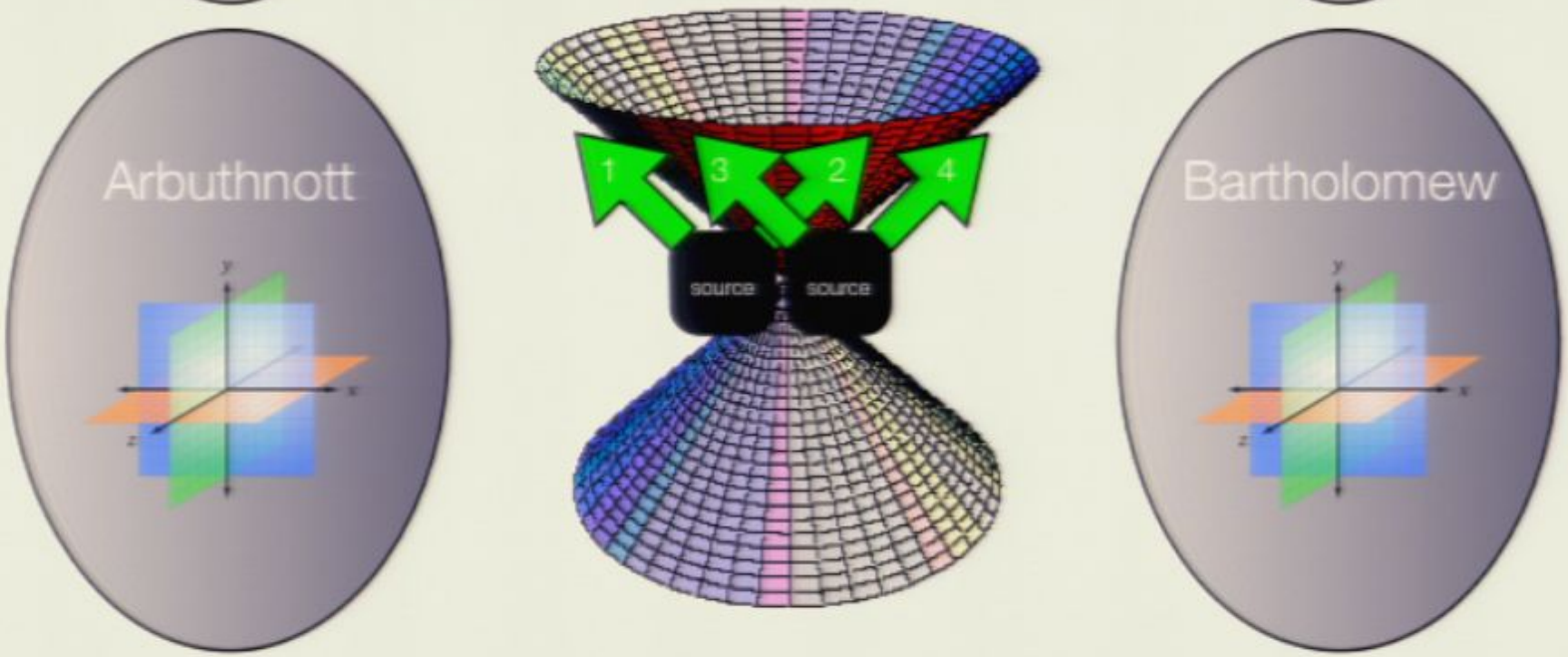
$$|-\rangle_1 \otimes |-\rangle_4, \quad |-\rangle_1 \otimes |+\rangle_4, \quad |+\rangle_1 \otimes |-\rangle_4, \quad |+\rangle_1 \otimes |+\rangle_4$$

implies implies implies implies

$$|+\rangle_2 \otimes |+\rangle_3, \quad |+\rangle_2 \otimes |-\rangle_3, \quad |-\rangle_2 \otimes |+\rangle_3, \quad |-\rangle_2 \otimes |-\rangle_3$$

M3 M2

Measure Z-component of spin of 2 and 3



$$|\Psi\rangle_{1234} = \frac{1}{2}\left(|+\rangle_1 \otimes |-\rangle_2 - |-\rangle_1 \otimes |+\rangle_2\right) \otimes \left(|+\rangle_3 \otimes |-\rangle_4 - |-\rangle_3 \otimes |+\rangle_4\right)$$

$|-\rangle_1 \otimes |-\rangle_4, \quad |-\rangle_1 \otimes |+\rangle_4, \quad |+\rangle_1 \otimes |-\rangle_4, \quad |+\rangle_1 \otimes |+\rangle_4$

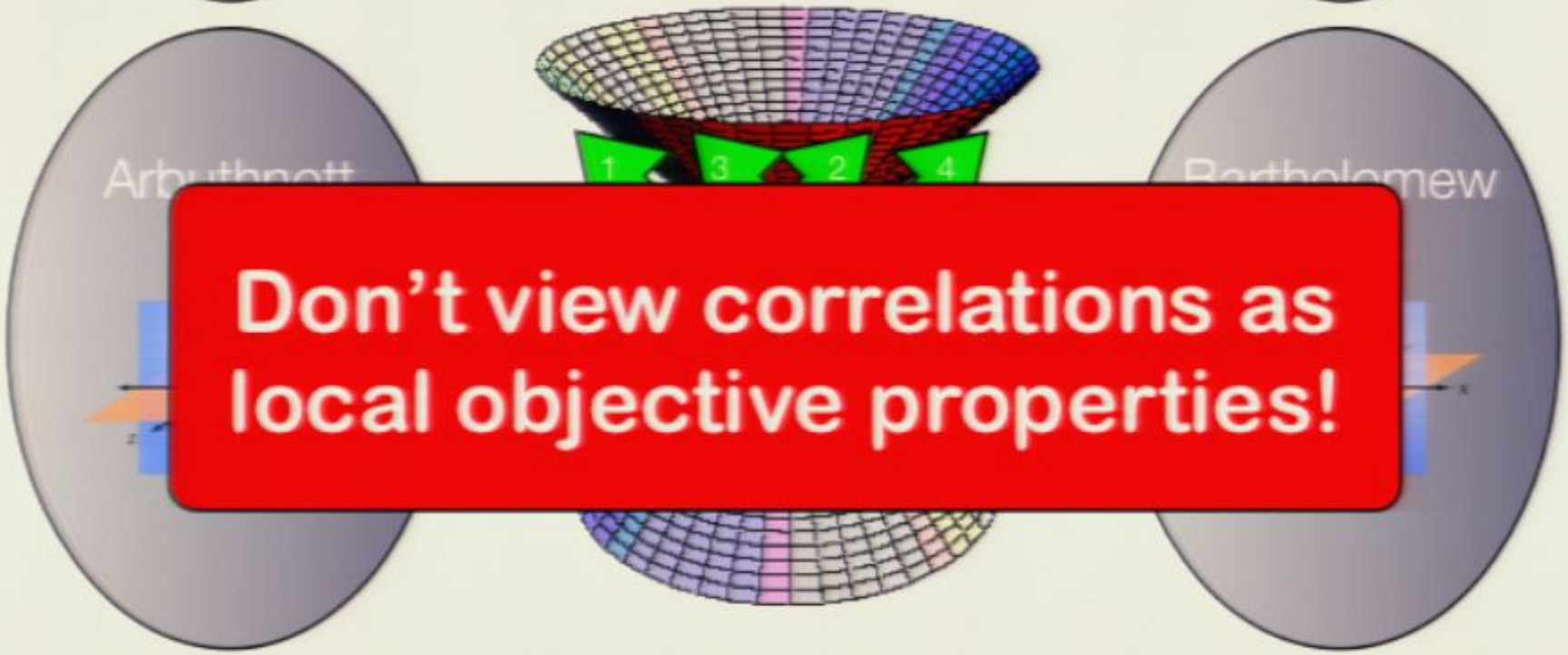
implies implies implies implies

$|+\rangle_2 \otimes |+\rangle_3, \quad |+\rangle_2 \otimes |-\rangle_3, \quad |-\rangle_2 \otimes |+\rangle_3, \quad |-\rangle_2 \otimes |-\rangle_3$

M3

M2

Measure Z-component of spin of 2 and 3

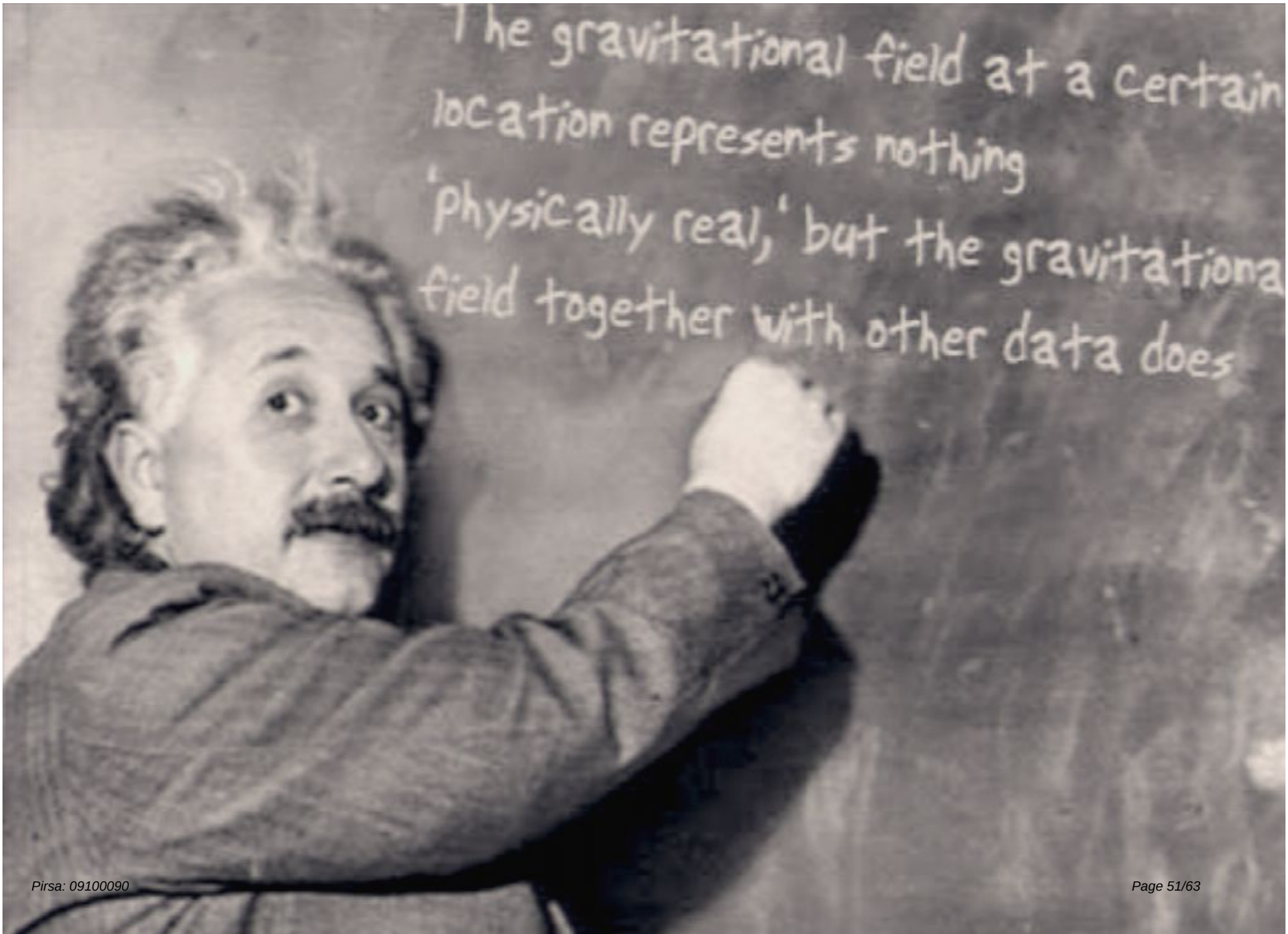


Don't view correlations as local objective properties!

$$|\Psi\rangle_{1234} = \frac{1}{2}\left(|+\rangle_1 \otimes |-\rangle_2 - |-\rangle_1 \otimes |+\rangle_2\right) \otimes \left(|+\rangle_3 \otimes |-\rangle_4 - |-\rangle_3 \otimes |+\rangle_4\right)$$

Barrett's Incoherence Objection

1. The idea of relations (correlations) without relata (correlata) is incoherent:
   - Relations are such that they supervene on the properties of the relata
2. Misreading of Mermin:
   - IIQM does involve relata as subjects of correlations
   - ... but they're unknowable
   - And they conflict with no-go theorems
3. IIQM went bust because it was based around isolated individual systems and their properties
   - Go structural instead [SIQM]!


The gravitational field at a certain
location represents nothing
'physically real,' but the gravitationa
field together with other data does

Partials and Completes

- Partial Observable: “a physical quantity to which we can associate a (measuring) procedure leading to a number” [“We will assume here, that one can associate to an arbitrary phase space function such a measuring procedure. A partial observable is then a phase space function, which does not need to be a Dirac observable, i.e. it does not have to commute with the constraints”]
- Complete Observable: “a quantity whose value [or PD] can be predicted by the theory” [“We will understand here under a complete observable phase space functions which commute (weakly) with the constraints, i.e. phase space functions, that are invariant under gauge transformations generated by the constraints.”]

Partials and Completes

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Kinematics

- Complete Observable: "a quantity whose value [or PD] can be predicted by the theory" ["We will understand here under a complete observable phase space functions which commute (weakly) with the constraints, i.e. phase space functions, that are invariant under gauge transformations generated by the constraints."]

Dynamics


The extended configuration space has a direct physical interpretation, as the space of the partial observables

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Complexus

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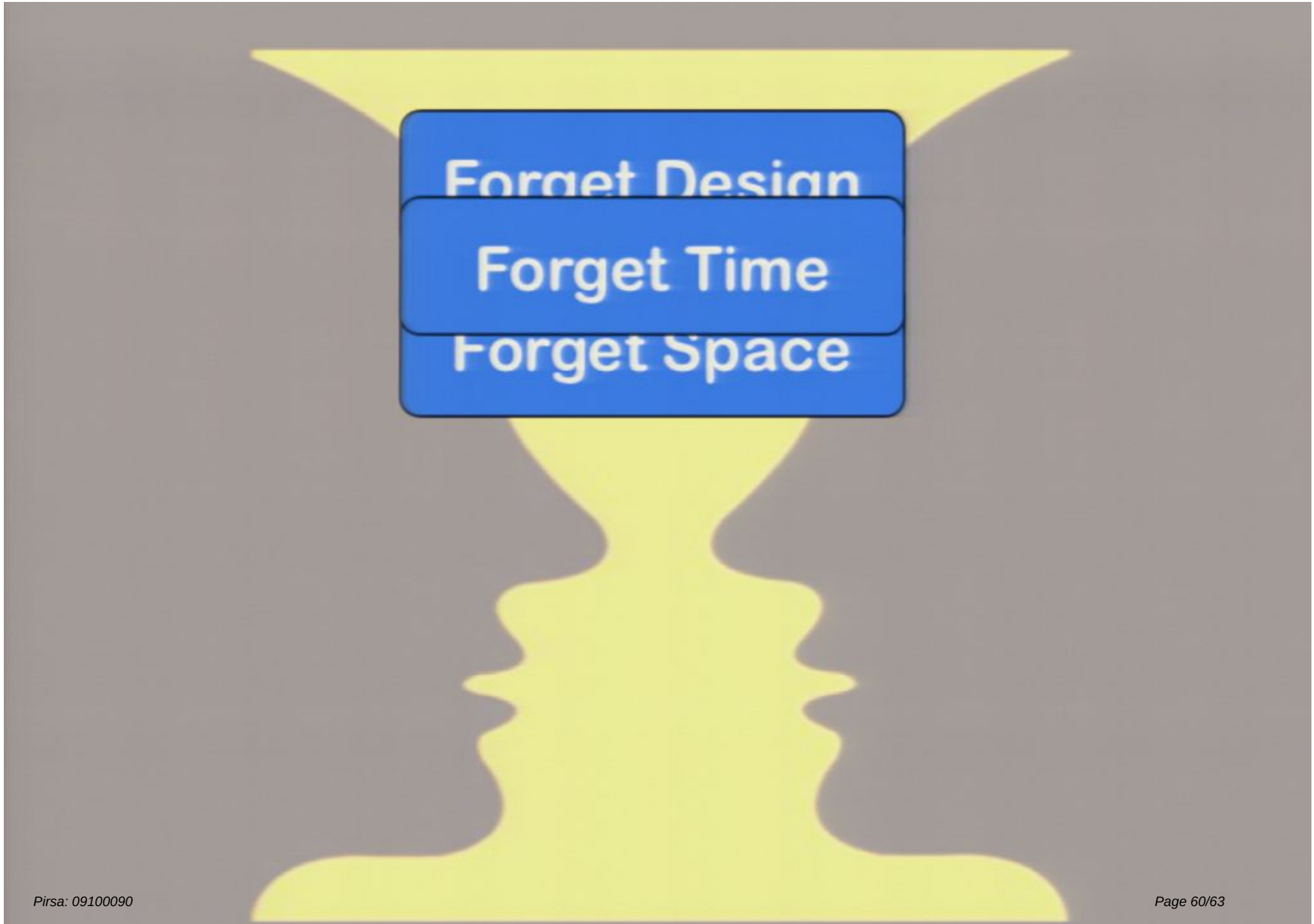
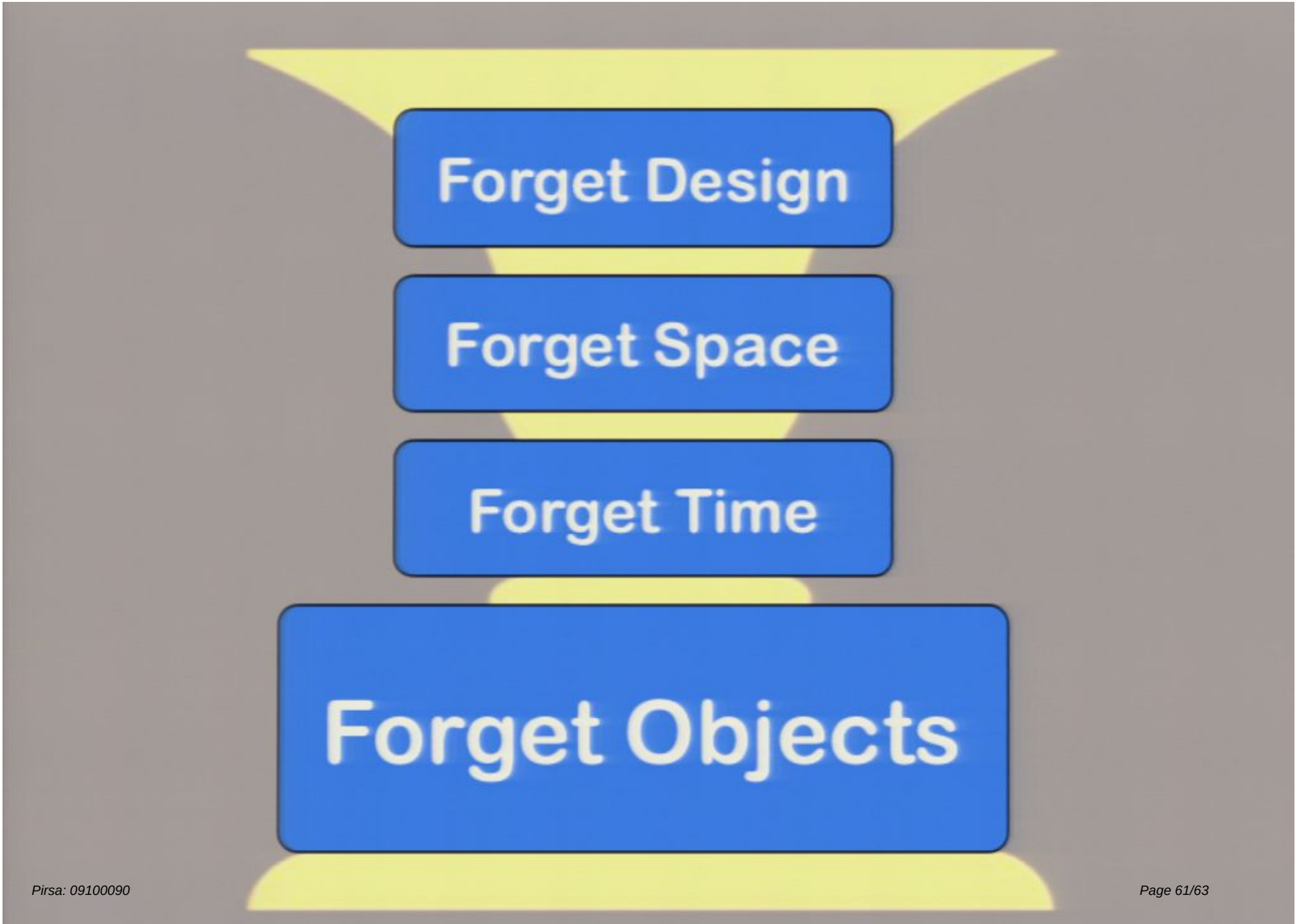

Forget Design
Forget Time
Forget Space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THE
BEABLES