Title: The Everett interpretation

Date: Sep 21, 2007 10:00 AM

URL: http://pirsa.org/07090069

Abstract: I shall present an overview of quantum mechanics in the Everett interpretation, that emphasises its structural characteristics, as a theory of what exists. In this respect it shares common ground with other fundamental theories in physics. As such its appeal is conservative; it makes do with the purely unitary equations of quantum mechanics as exceptionless and universal. It also makes do with standard methods for extracting \'high level\' or \'emergent\' ontology, the furniture of macroscopic worlds, from largish molecules on up. It would appeal all the more if it made do with standard epistemological principles too - for example, in the context of inductive statistical confirmation, with standard Bayesian epistemology. But this links to the question of the interpretation of probability in the Everett interpretation, and here the theory seems anything but conservative. It is a common complaint that the approach leaves no room at all for talk of uncertainty. I shall argue, again on conservative interpretative practises, that this claim is incorrect. Chance events are, indeed, revealed in a surprising light - as quantum branchings - but they are the more perspicuous, and their properties and quantitative measure better explained, in light of that.

The Everett interpretation:

Simon Saunders

Oxford University

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The Everett interpretation: a user's manual

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http://users.ox.ac.uk/~everett/

Why many worlds?

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Why many worlds?

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To solve the measurement problem

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The problem of how to relate the (unitary, deterministic) equations of motion of quantum mechanics to observed phenomena

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- The theory is to apply universally

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- Without any special mention of 'the observer' or 'measurement'

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The problem of how to relate the (unitary, deterministic) equations of motion of quantum mechanics to observed phenomena

- The theory is to apply universally
- Without any special mention of 'the observer' or 'measurement'
- And without any special interpretative assumptions or additional equations

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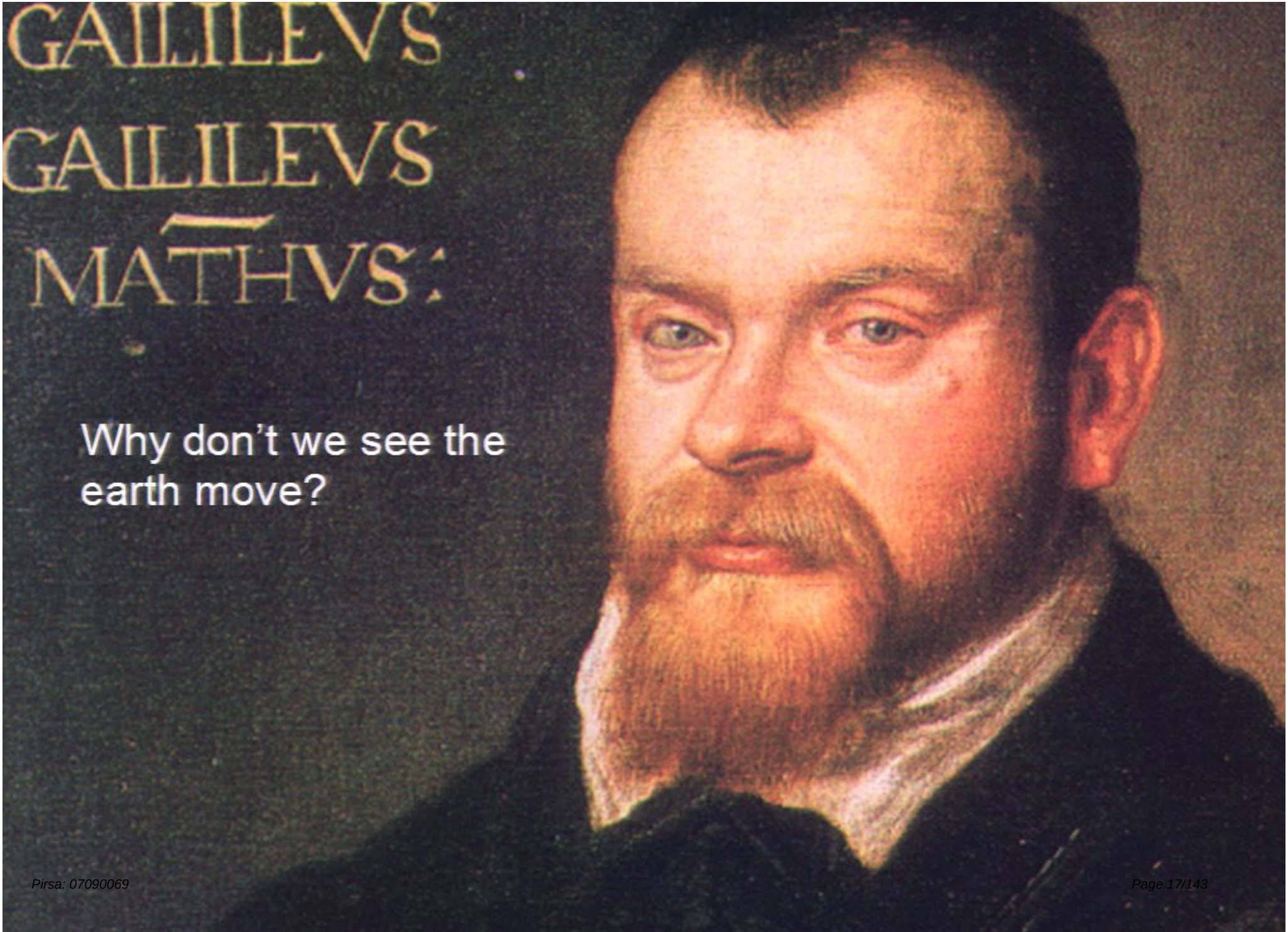
MATHVS:


GAILILEVS
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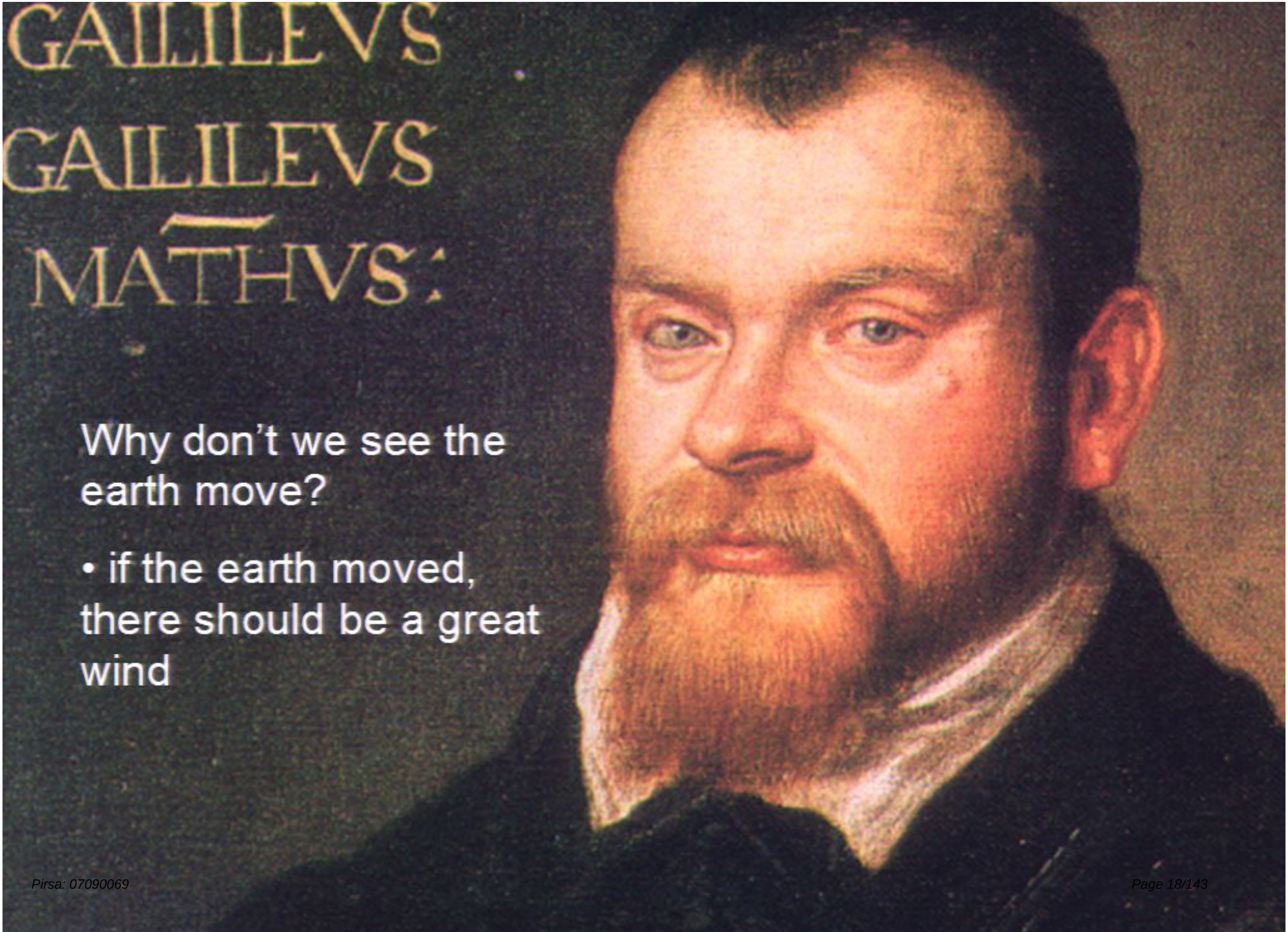
MATHVS:
Why don't we see the earth move?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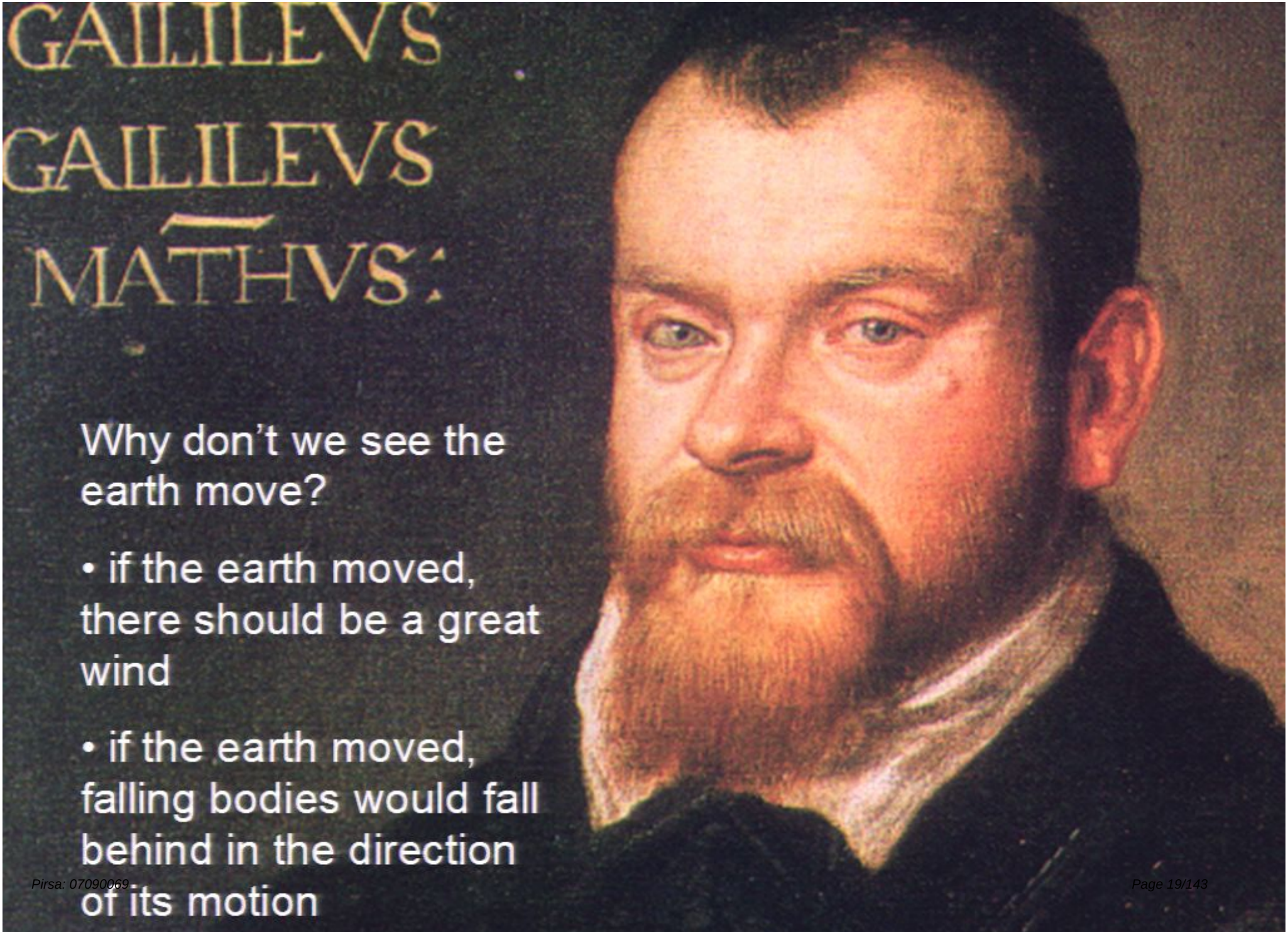
Why don't we see the earth move?
• if the earth moved, there should be a great wind


GAILILEVS
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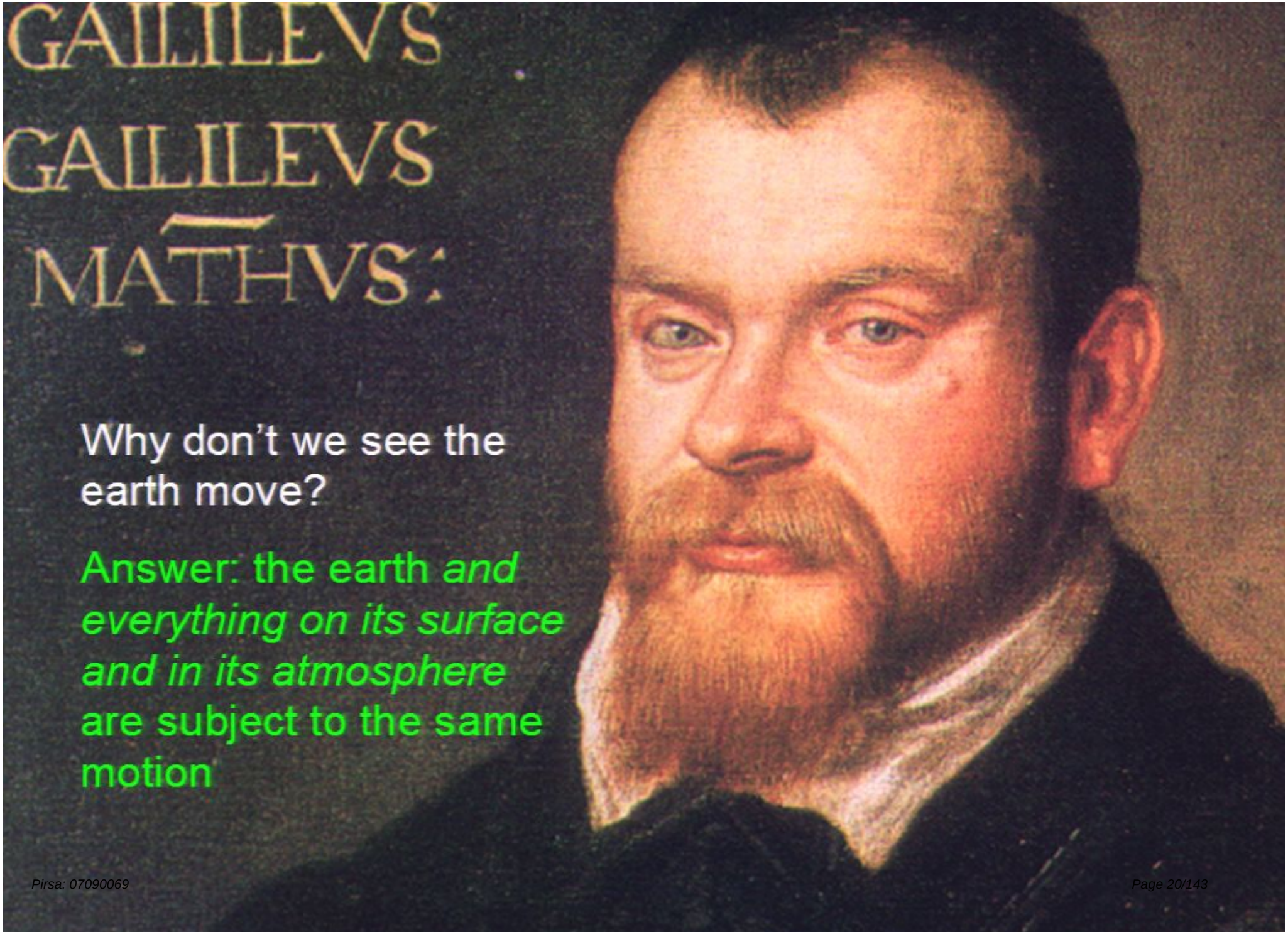
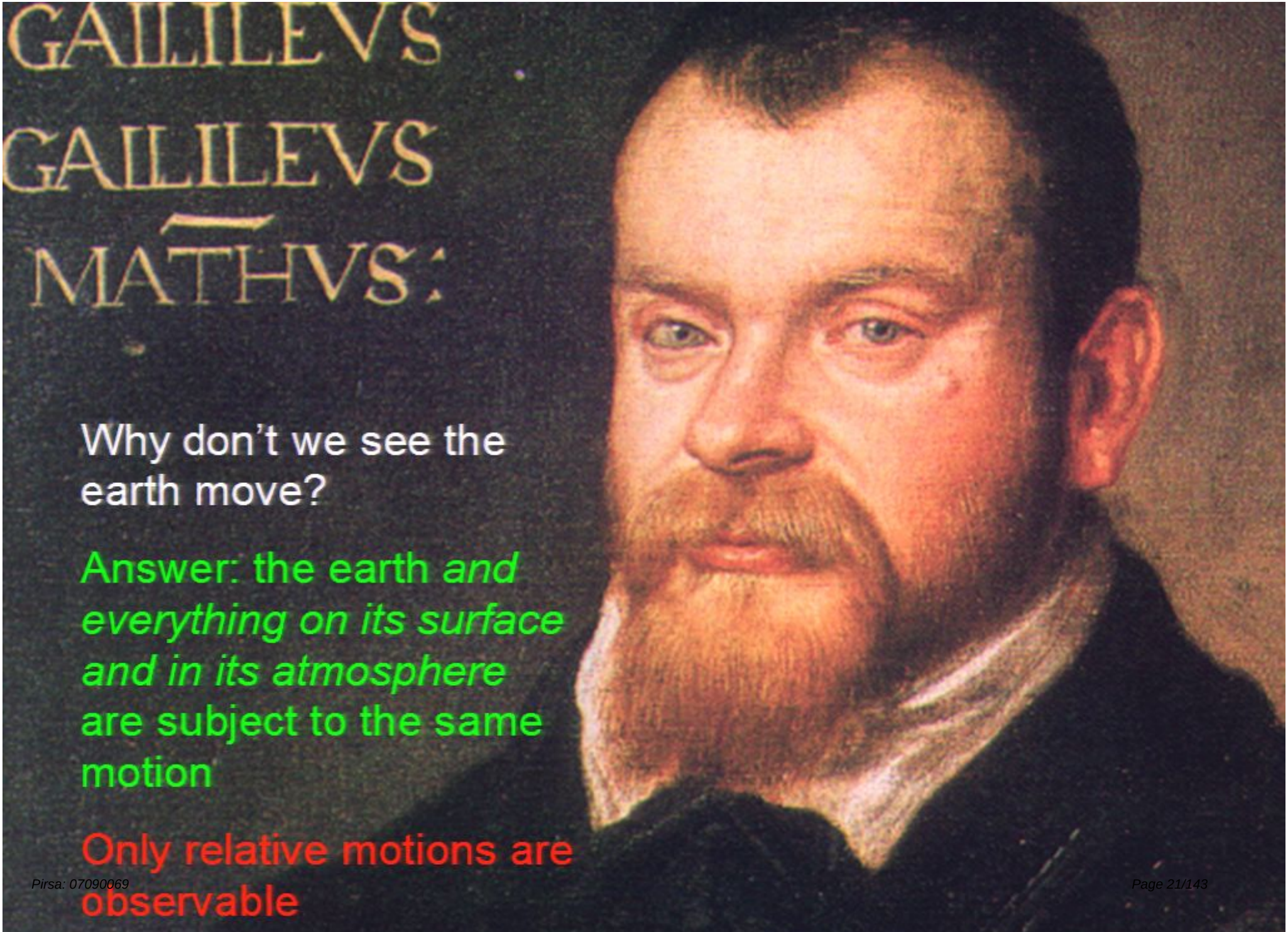
MATHVS:
Why don't we see the earth move?
• if the earth moved, there should be a great wind
• if the earth moved, falling bodies would fall behind in the direction of its motion



Why don't we see the earth move?

Answer: the earth *and everything on its surface and in its atmosphere* are subject to the same motion



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Only relative motions are observable

Everett

Everett

Why don't we see superpositions?

Everett

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- if there are only superpositions, we would all turn into blacmange

Everett

Why don't we see superpositions?

- if there are only superpositions, we would all turn into blacmange
- if there are only superpositions, there would be no meaning to probability

Everett

Why don't we see superpositions?

Answer: when macroscopic superpositions arise, everything enters into the superposition, including the apparatus and the environment

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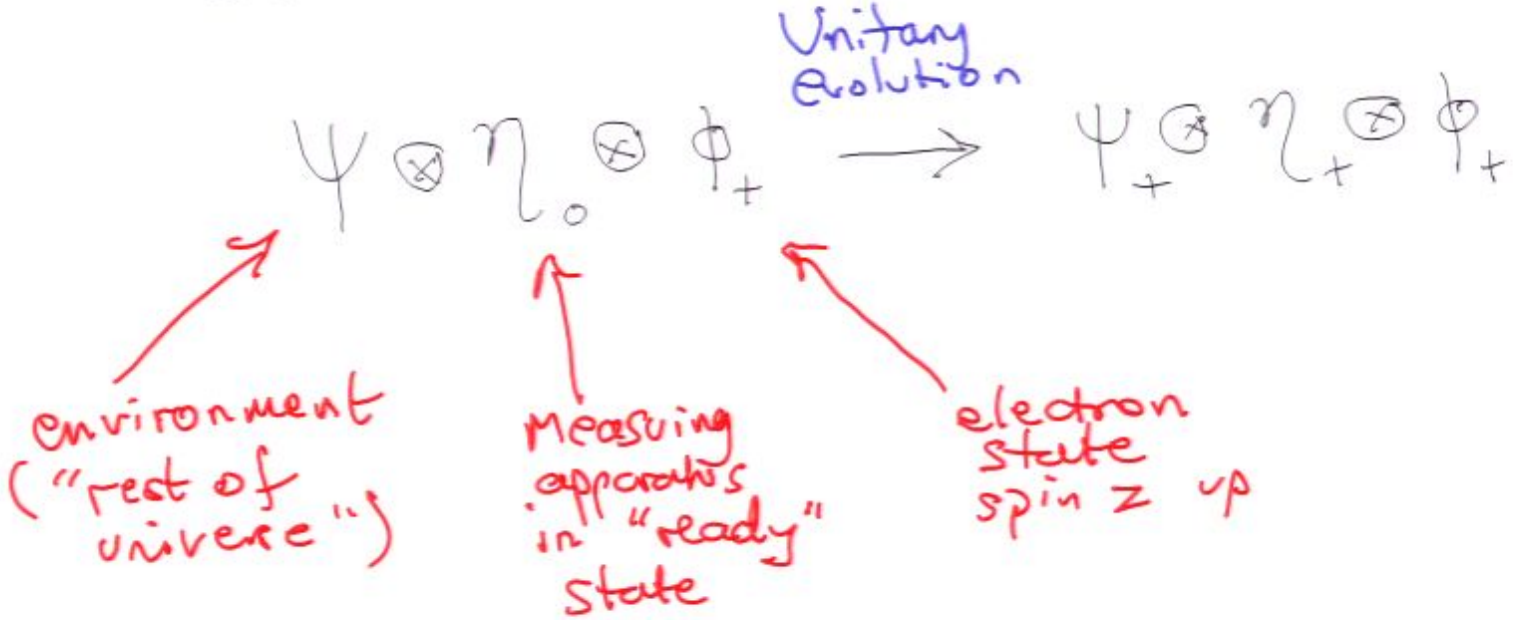
Only correlations are observable

Stern-Gerlach expt



Stern-Gerlach expt

$$\psi \otimes \eta_0 \otimes \phi_+ \longrightarrow \psi_+ \otimes \eta_+ \otimes \phi_+$$

Some coupling between apparatus and environment

apparatus records 'Spin z-up'

$$\psi \otimes \eta_0 \otimes (c_+ \phi_+ + c_- \phi_-)$$

$$\longrightarrow \psi \otimes (c_+ \eta_+ \otimes \phi_+ + c_- \eta_- \otimes \phi_-)$$

$$\longrightarrow c_+ \psi_+ \otimes \eta_+ \otimes \phi_+ + c_- \psi_- \otimes \eta_- \otimes \phi_-$$

'Relative state' of η_+ is ϕ_+

" " " η_- is ϕ_-

$$\psi \otimes \eta_0 \otimes (c_+ \phi_+ + c_- \phi_-) \otimes (c_+ \phi_+ + c_- \phi_-)$$

$$\rightarrow \psi \otimes \Big(c_+ c_+ \eta_{++} \otimes \phi_+ \otimes \phi_+ + c_+ c_- \eta_{+-} \otimes \phi_+ \otimes \phi_- + c_- c_+ \eta_{-+} \otimes \phi_- \otimes \phi_+ + c_- c_- \eta_{--} \otimes \phi_- \otimes \phi_- \Big)$$

$\rightarrow$ etc.

measurement device displays record of outcome 'spin up' followed by 'spin down'

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$$\rightarrow \psi \otimes \left(c_+ c_+ \eta_{++} \otimes \phi_+ \otimes \phi_+ + c_+ c_- \eta_{+-} \otimes \phi_+ \otimes \phi_- \right.$$

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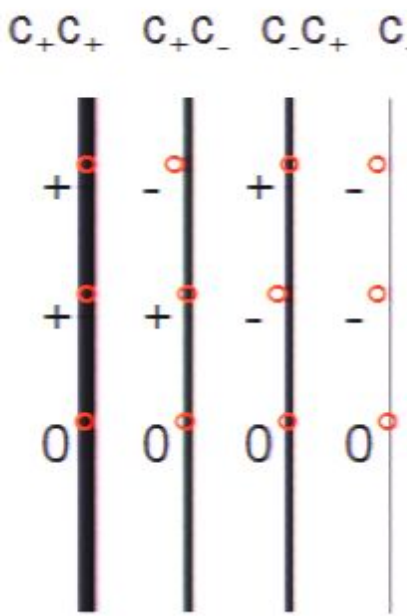
$\rightarrow$ etc.



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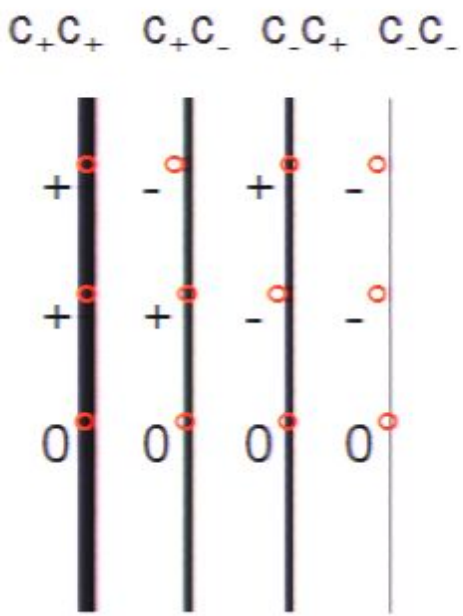
Why many worlds?

To solve the measurement problem…

Universality • no mention of measurement • no special interpretative assumption or additional eqs



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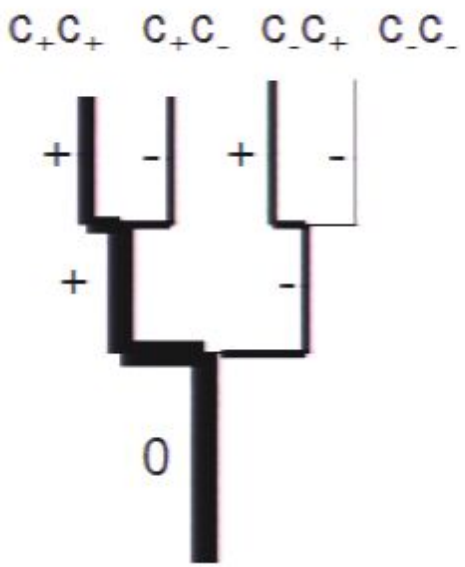

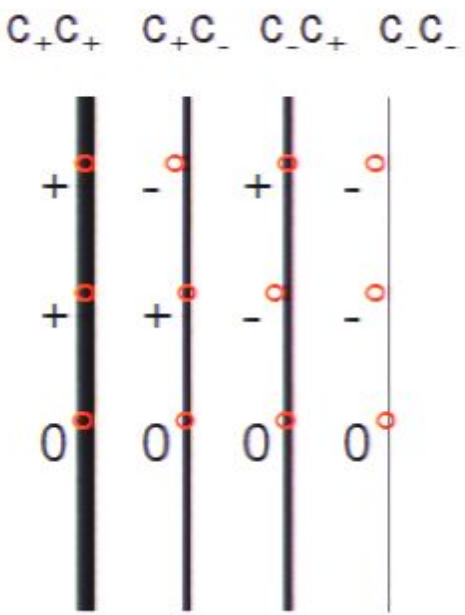

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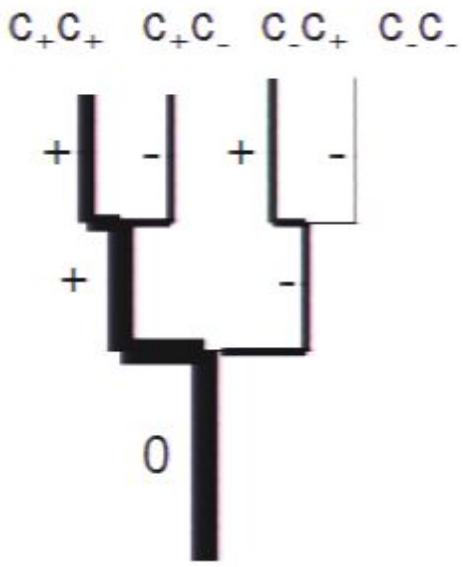

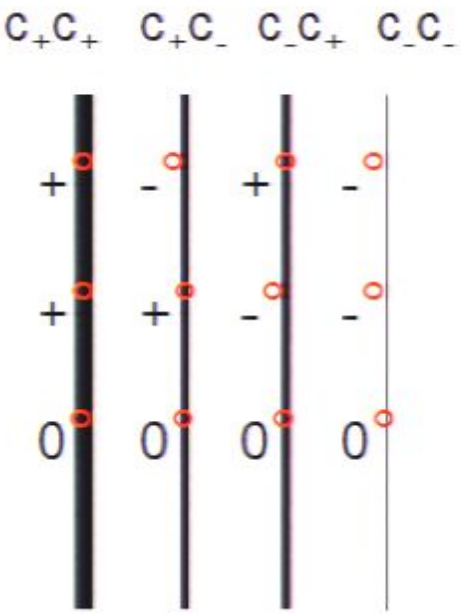

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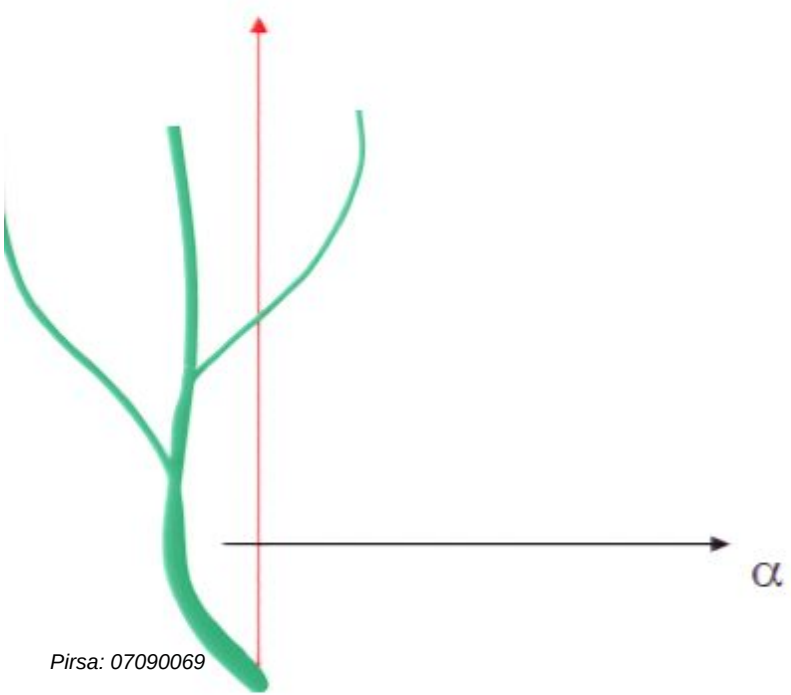

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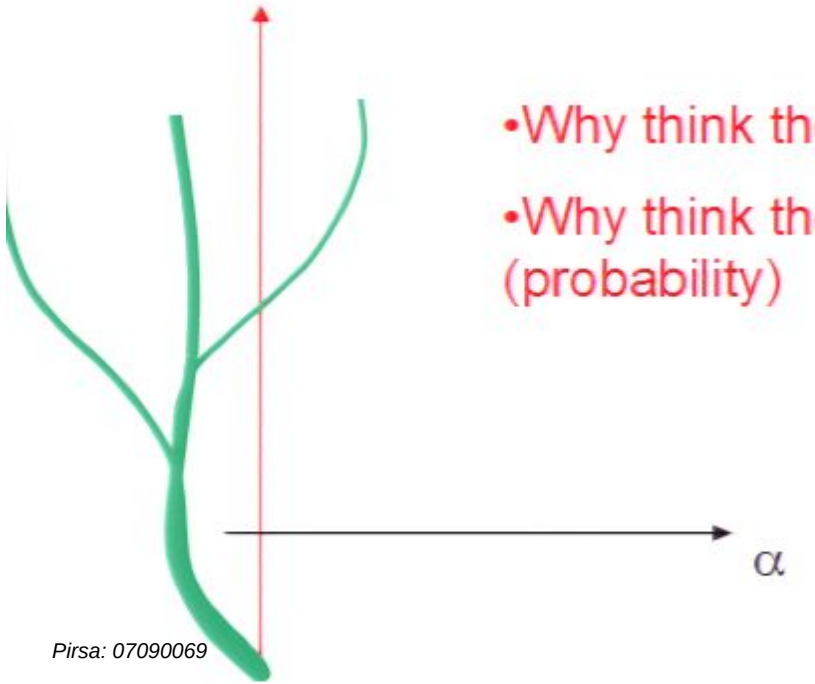
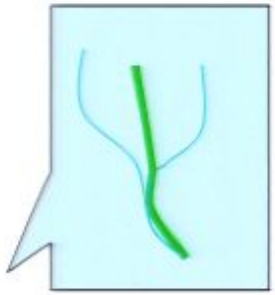
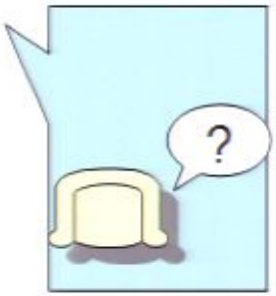


- Why think there is a branching structure at all? (ontology)
- Why think there are probabilities in the theory at all? (probability)

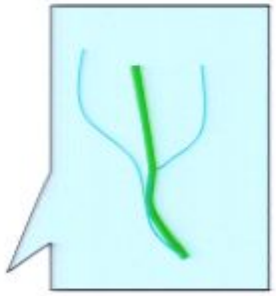


- Ontology

- Probability



Incoherence problem



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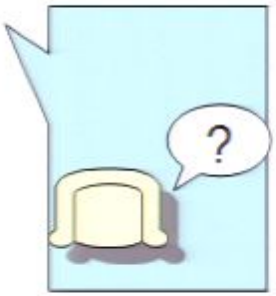
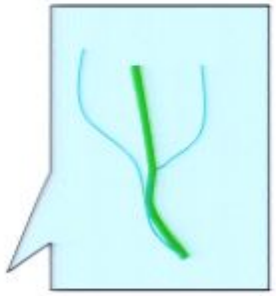


Incoherence problem

quantitative problem



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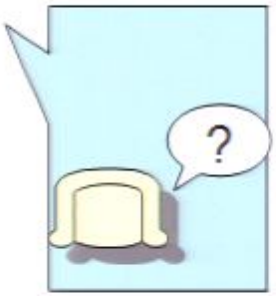

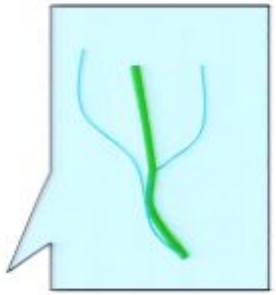

•Ontology

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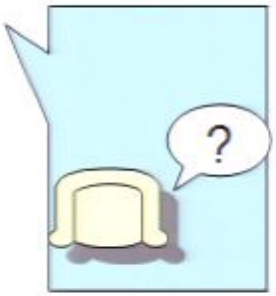

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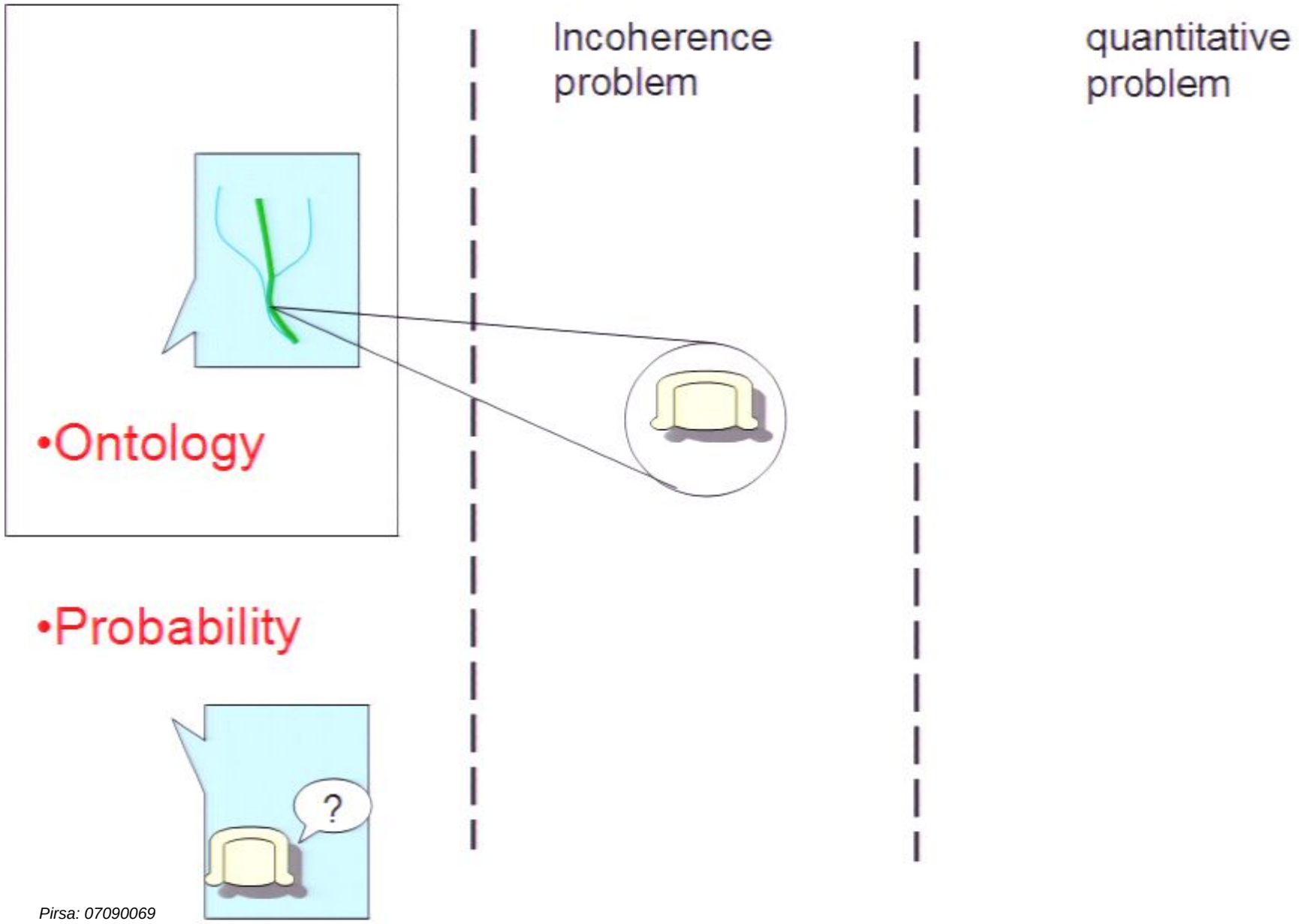
Incoherence problem
quantitative problem
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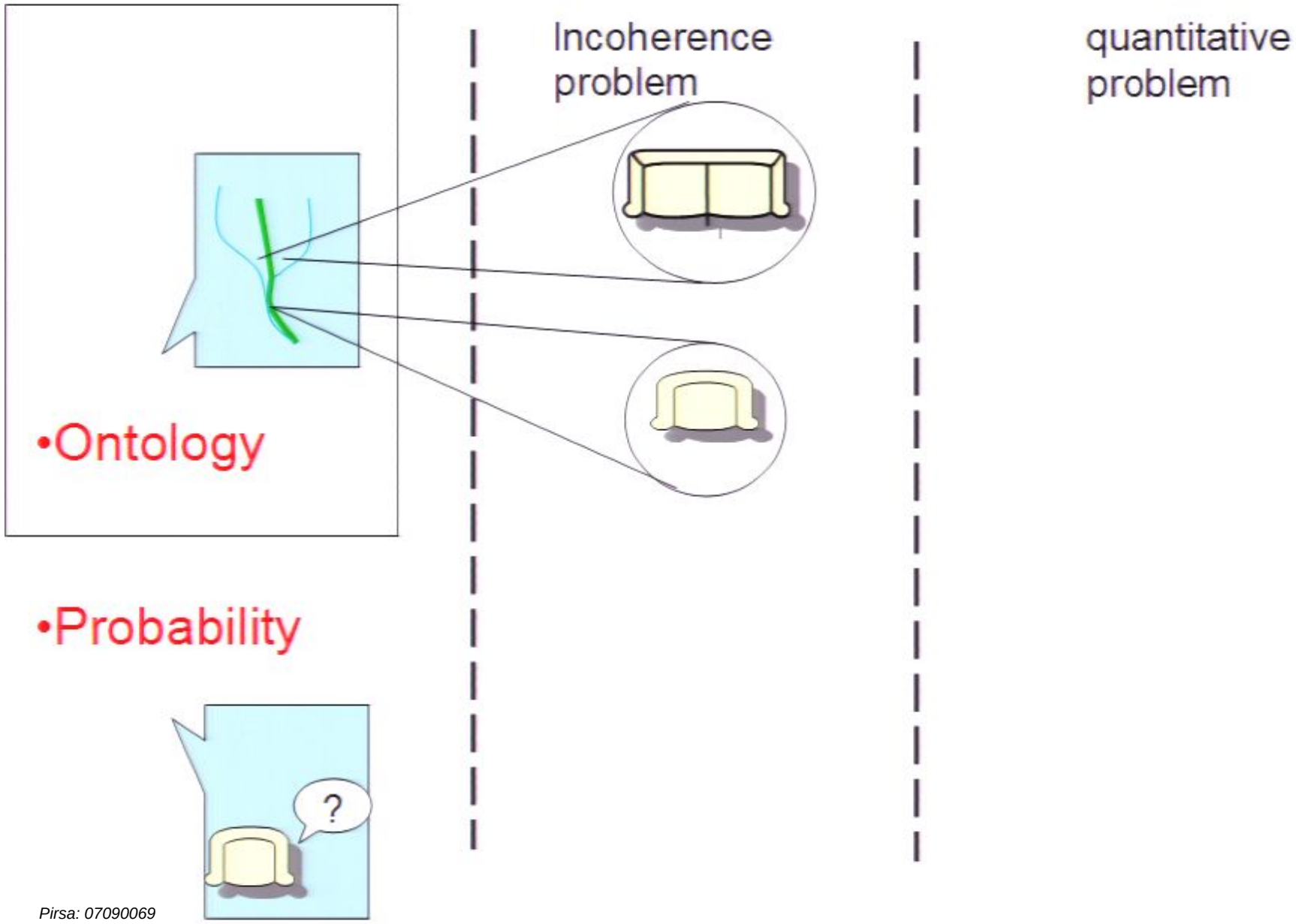
?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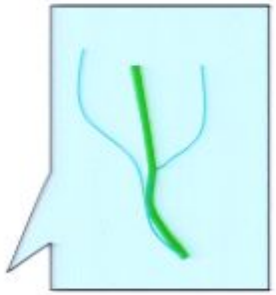

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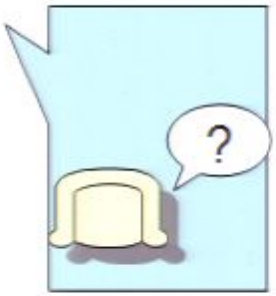

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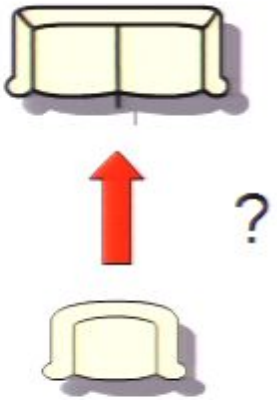
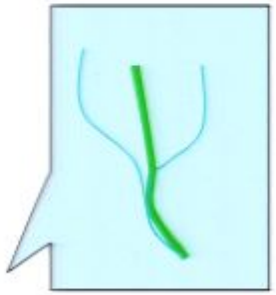


quantitative problem



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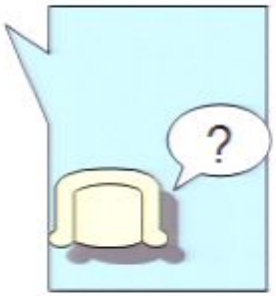

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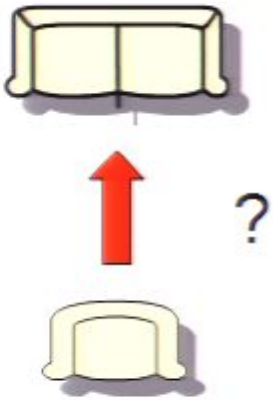
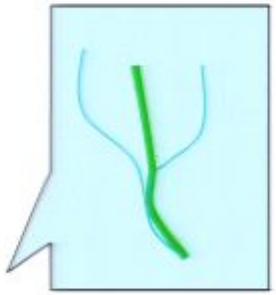


the problem arises with *any* materialistic theory of the self

quantitative problem



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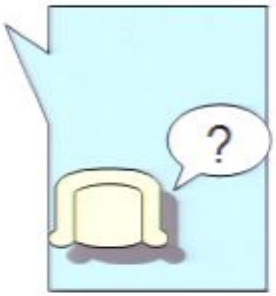

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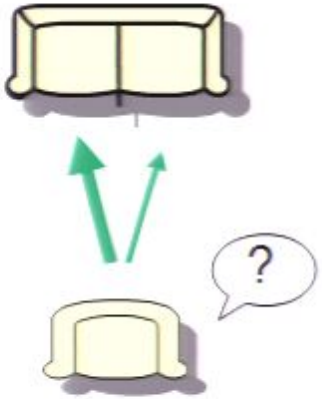
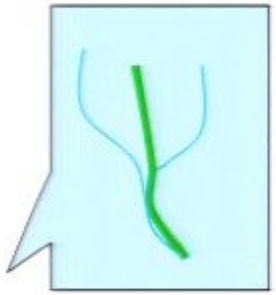


quantitative problem

suppose solved



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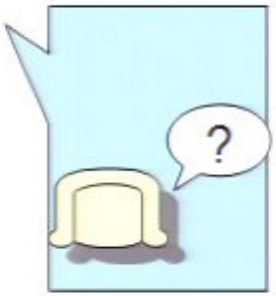

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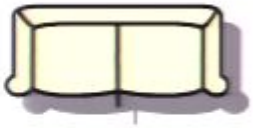

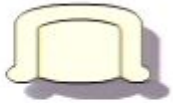

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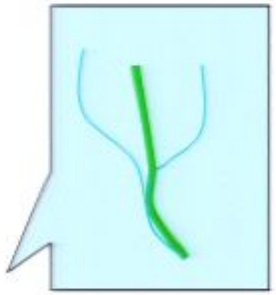

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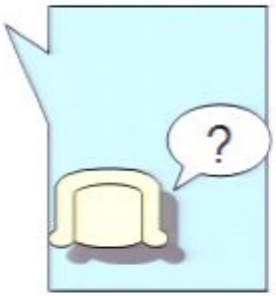

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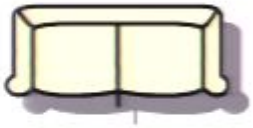
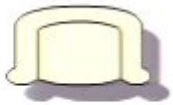


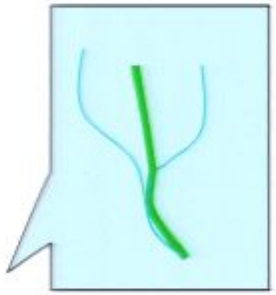


Uncertainty intelligible- 'chance'

Uncertainty unintelligible- 'caring measure'

quantitative problem

suppose solved



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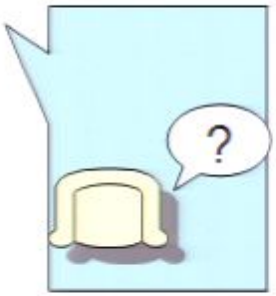
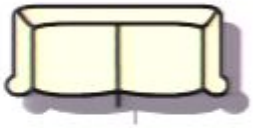
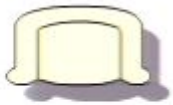


Incoherence problem





Uncertainty intelligible- 'chance'

Uncertainty unintelligible- 'caring measure'

quantitative problem

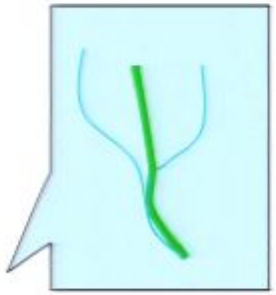
Given the ontology

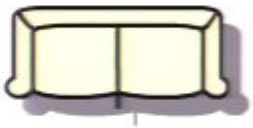
Not given the ontology

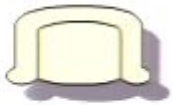
suppose solved

Incoherence problem

quantitative problem

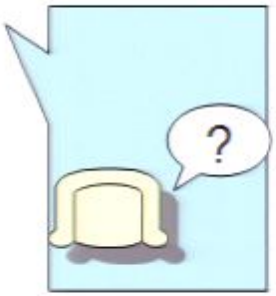






•Ontology

•Probability



Uncertainty intelligible- 'chance'

Given the ontology

practical problem

Uncertainty unintelligible- 'caring measure'

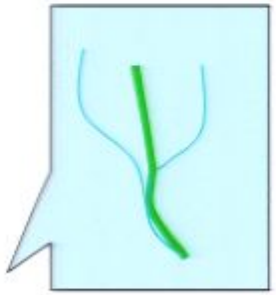
Not given the ontology

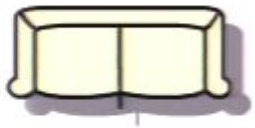
epistemic problem

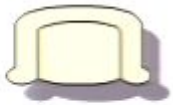
suppose solved

Incoherence problem

quantitative problem

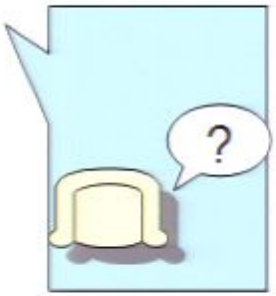






•Ontology

•Probability



Uncertainty intelligible- 'chance'

Given the ontology

practical problem

Uncertainty unintelligible- 'caring measure'

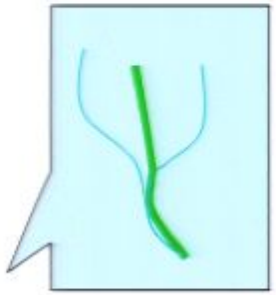
Not given the ontology

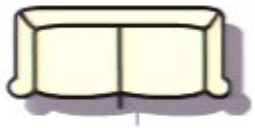
epistemic problem solved

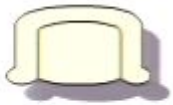
suppose solved

Incoherence problem

quantitative problem

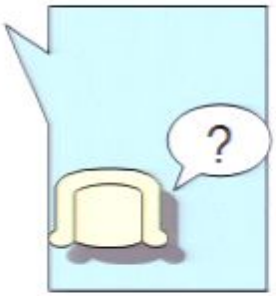






•Ontology

•Probability



Uncertainty intelligible- 'chance'

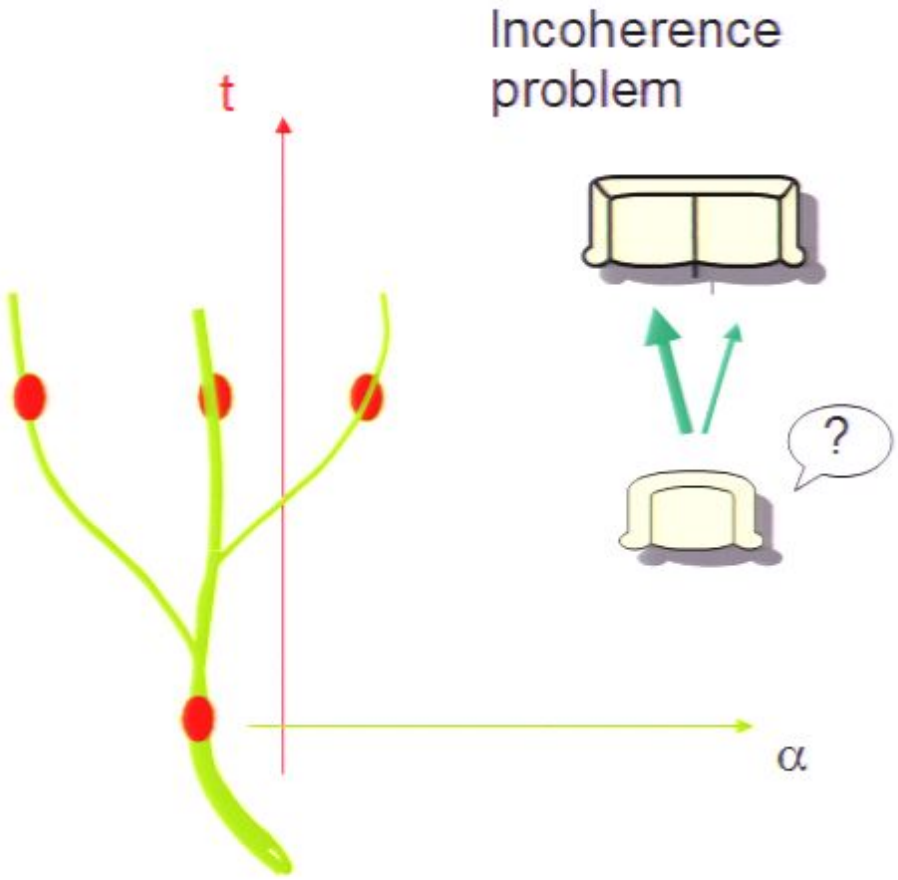
Uncertainty unintelligible- 'caring measure'

Given the ontology

Not given the ontology

practical problem solved

epistemic problem solved


Incoherence
problem
t
?
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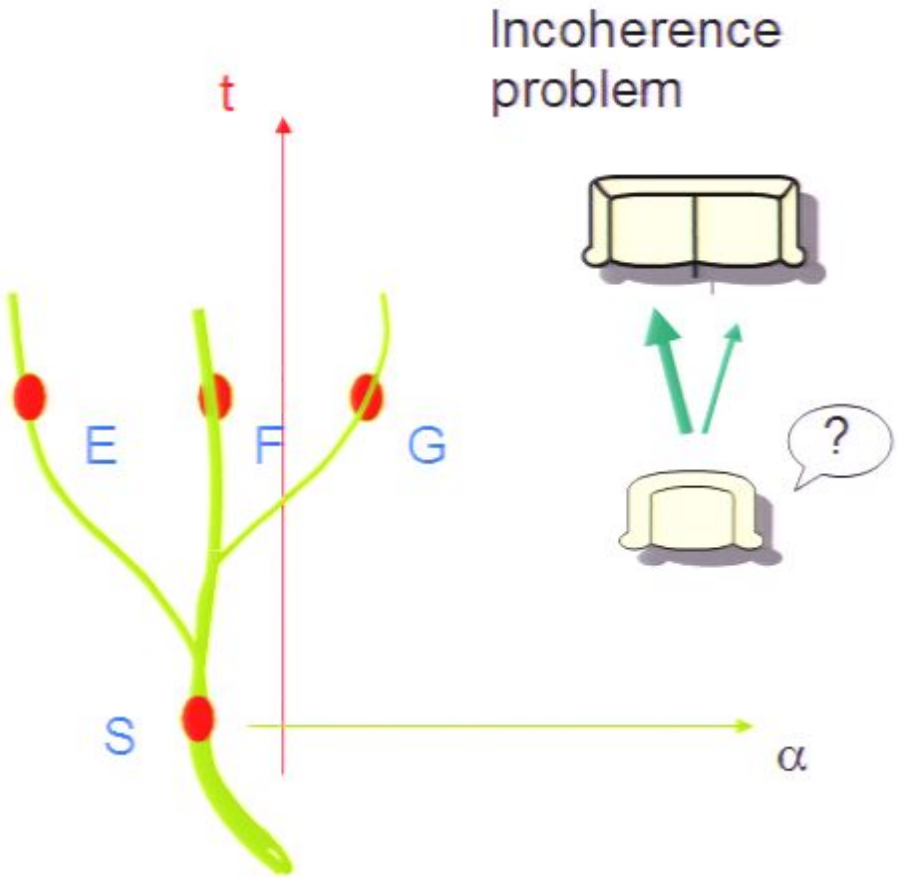
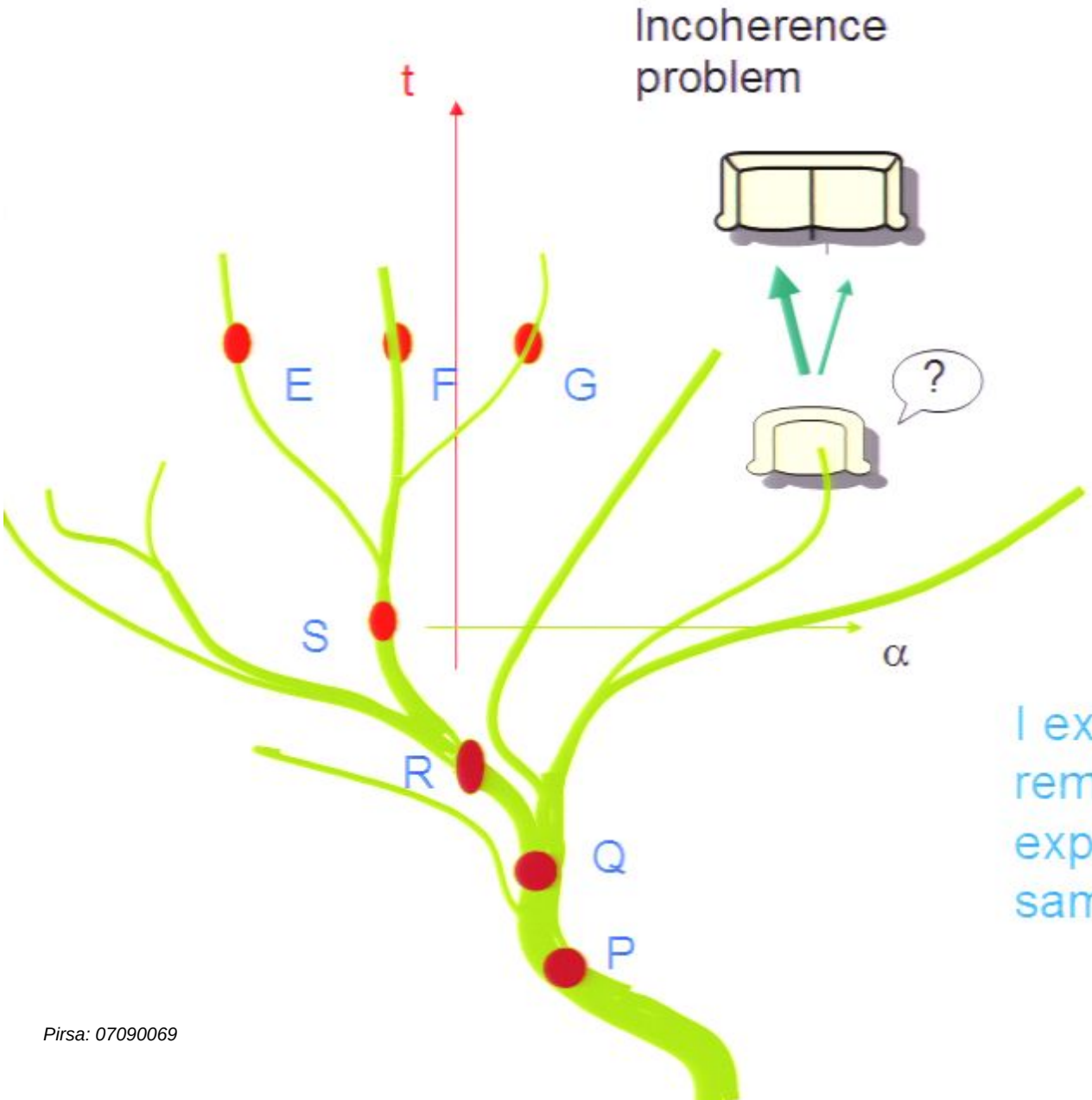
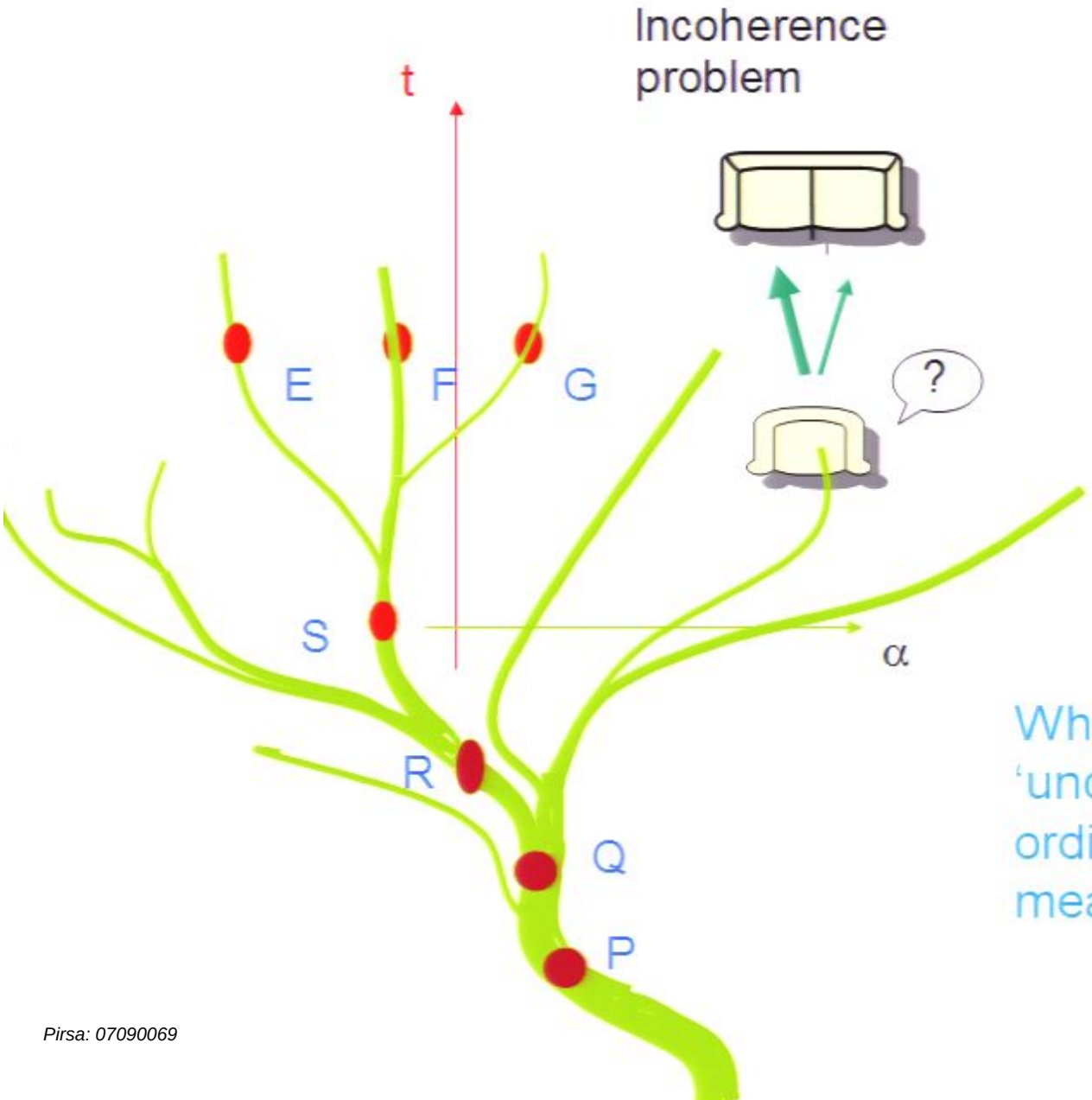


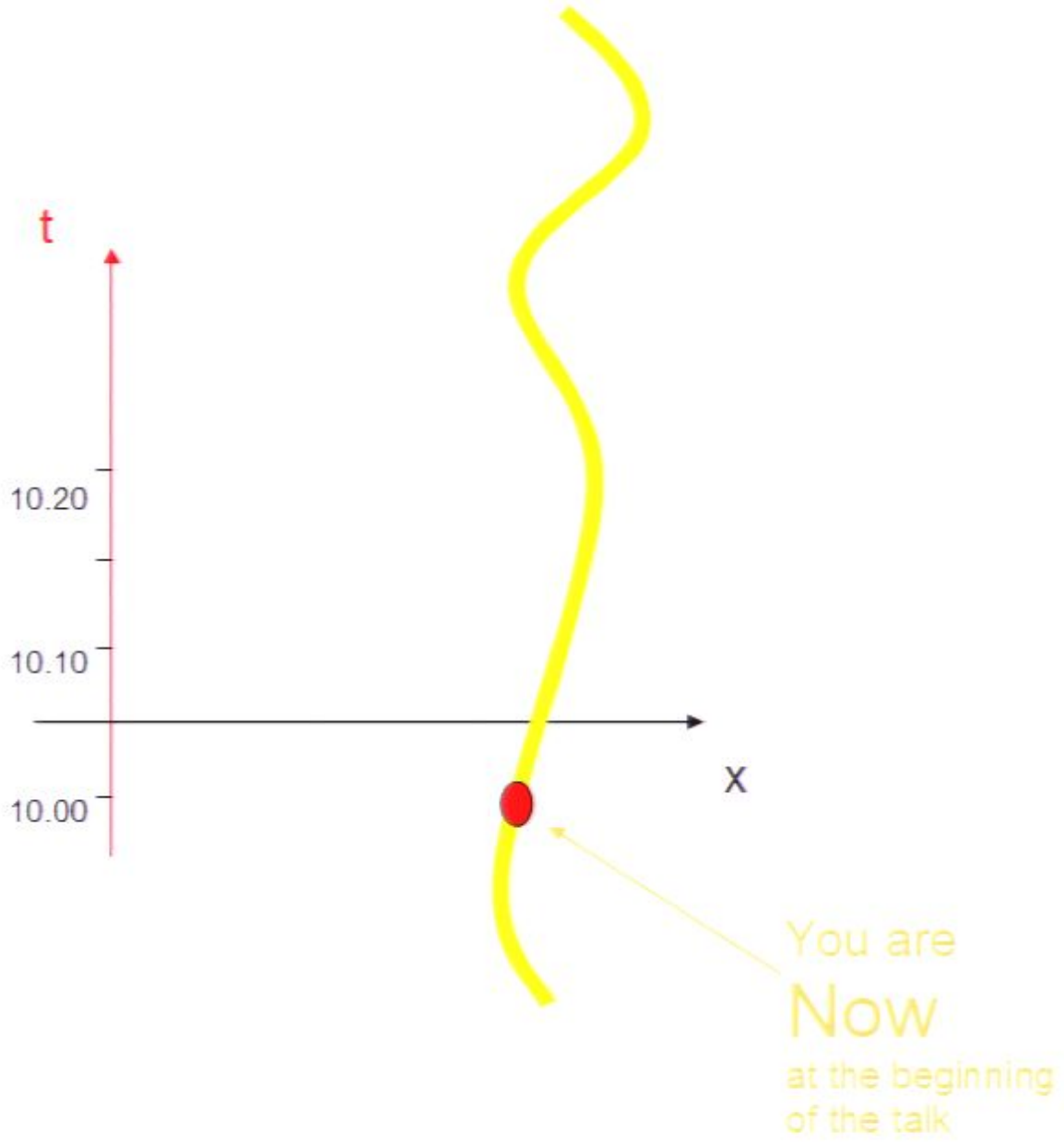
I expect what I remember – I expect more of the same



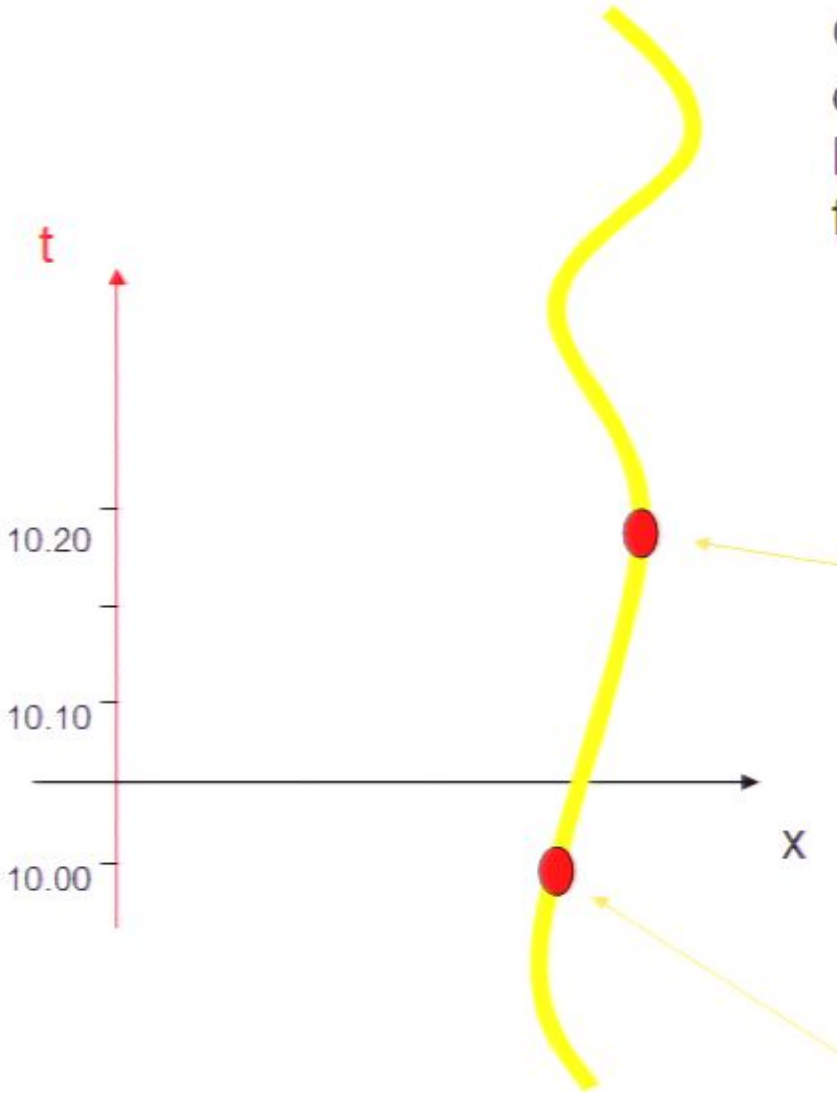
I expect what I remember – I expect more of the same



What do words like 'uncertainty' (as ordinarily used) mean anyway?

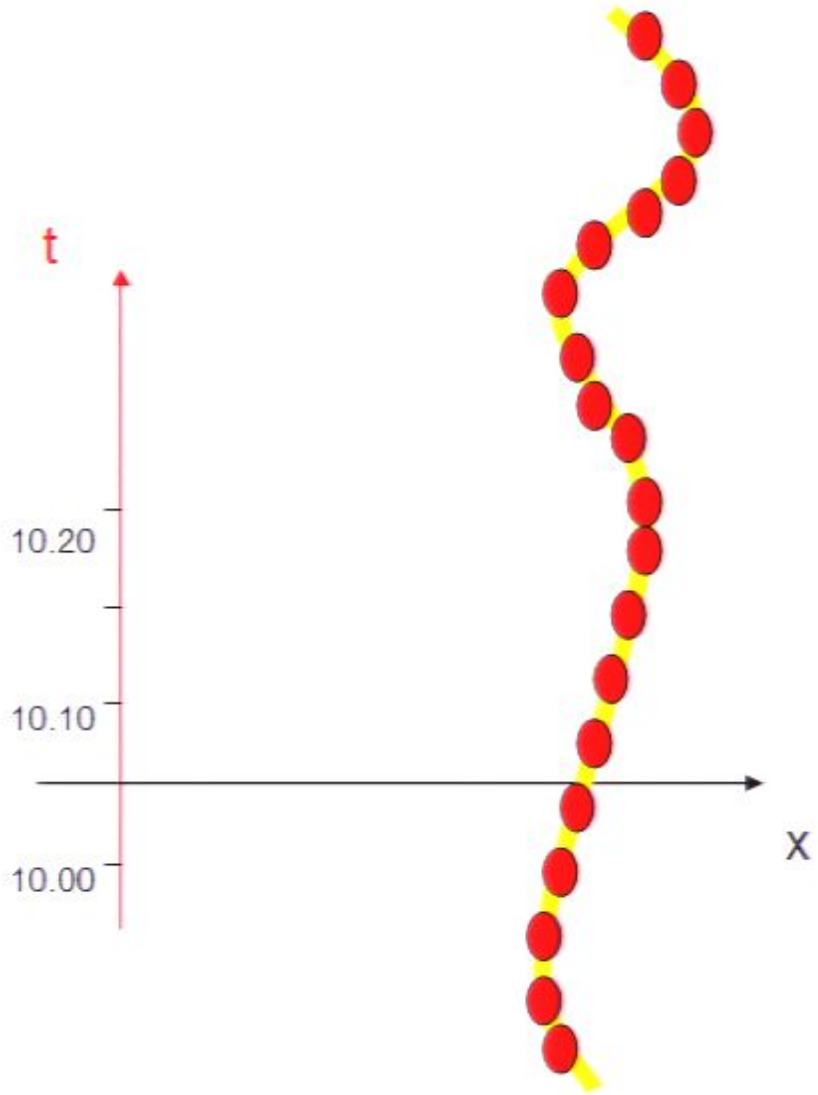

t
10.20
10.10
10.00
x
You are
Now
at the beginning
of the talk

The world is, it does not happen. Only to the gaze of consciousness, crawling up the life-line of your body, does it fleetingly come to life (Weyl)



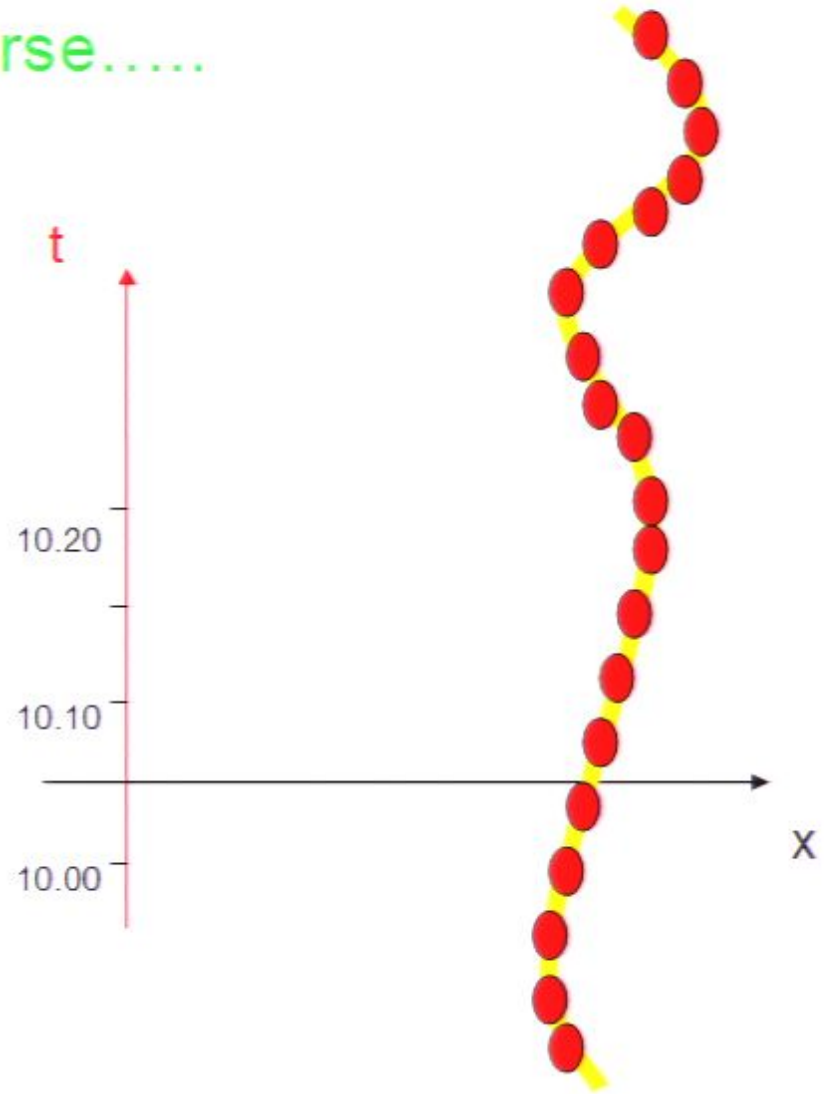
You are
Now
near the middle of the talk

You are
Now
at the beginning of the talk

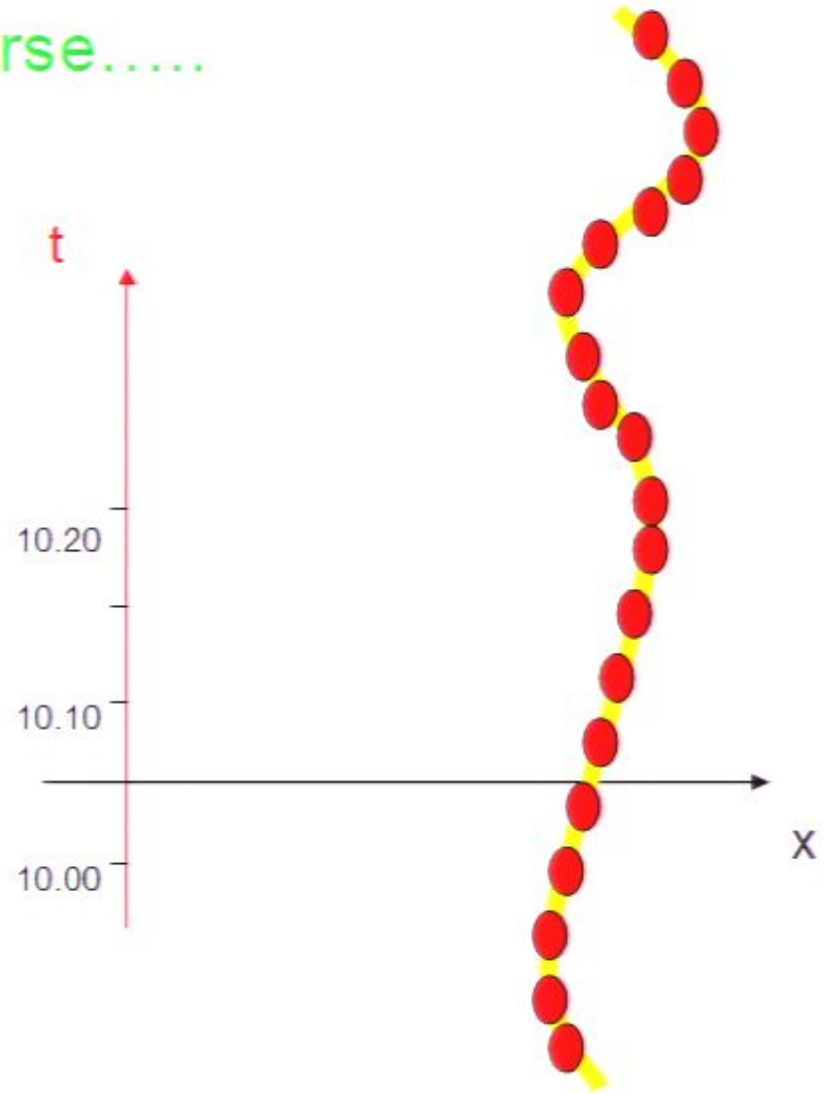

t
10.20
10.10
10.00
x

In a block universe.....

There is no change



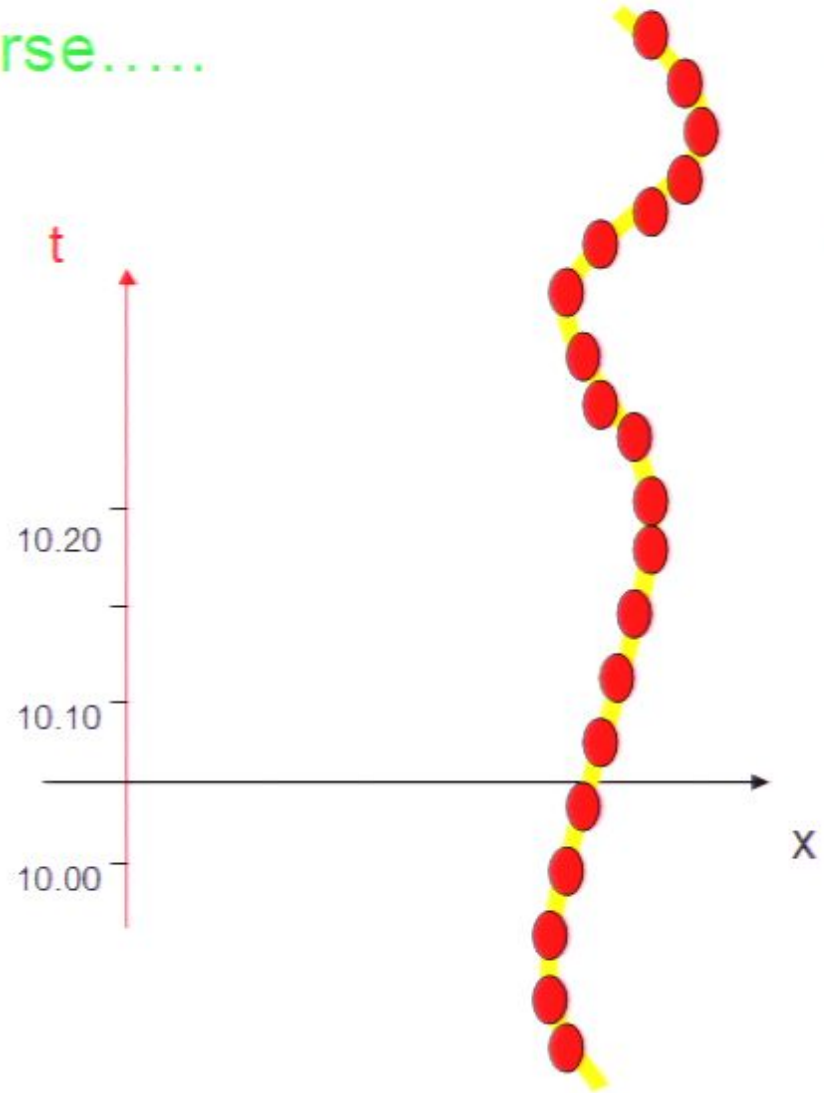
In a block universe.....



There is no change

- Time does not flow
- There is no becoming

In a block universe.....

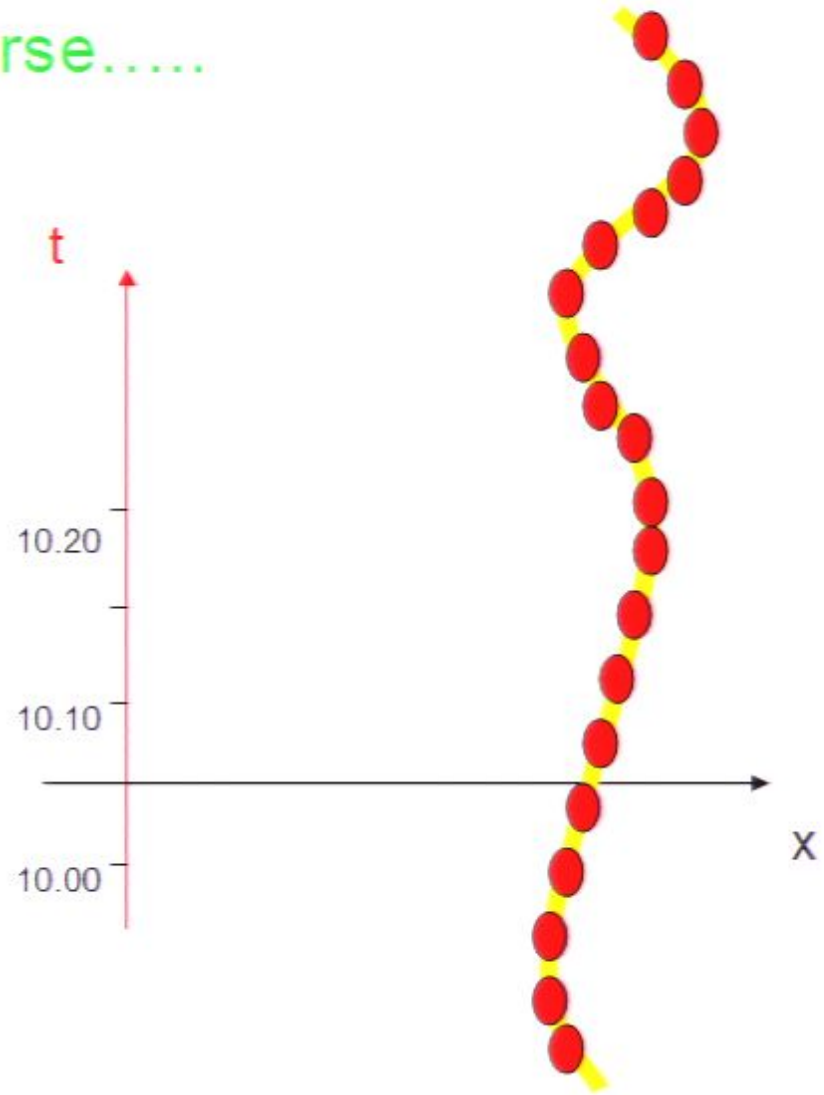


There is no change

- Time does not flow
- There is no becoming
- There is no free-will

Alternatively:

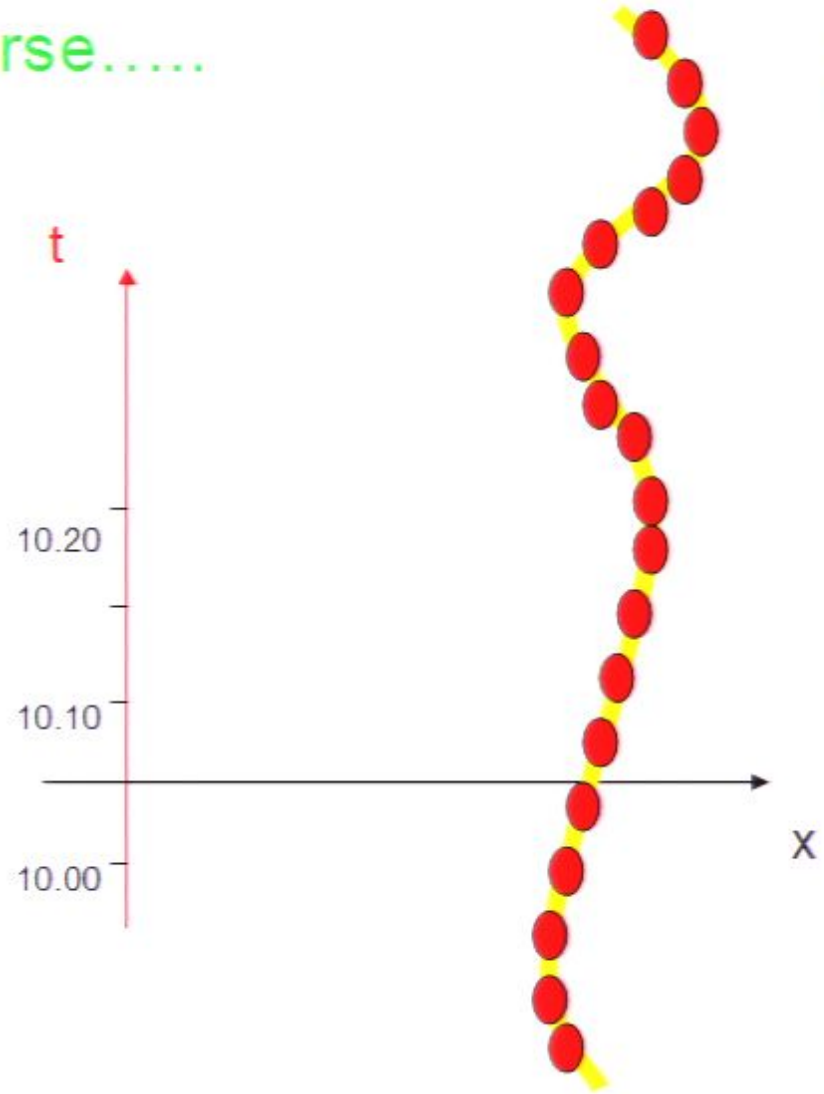
In a block universe.....



Alternatively:

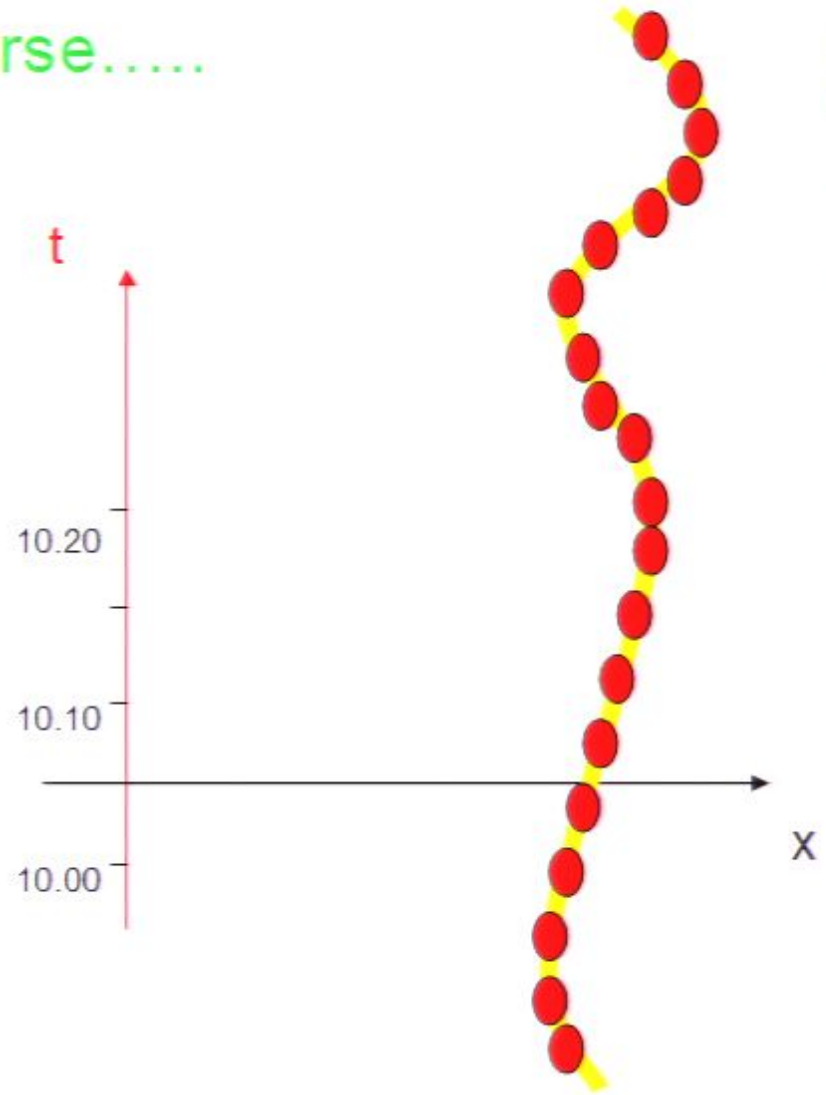
In a block universe…..

Change resides in the relations among events throughout your life-line



Alternatively:

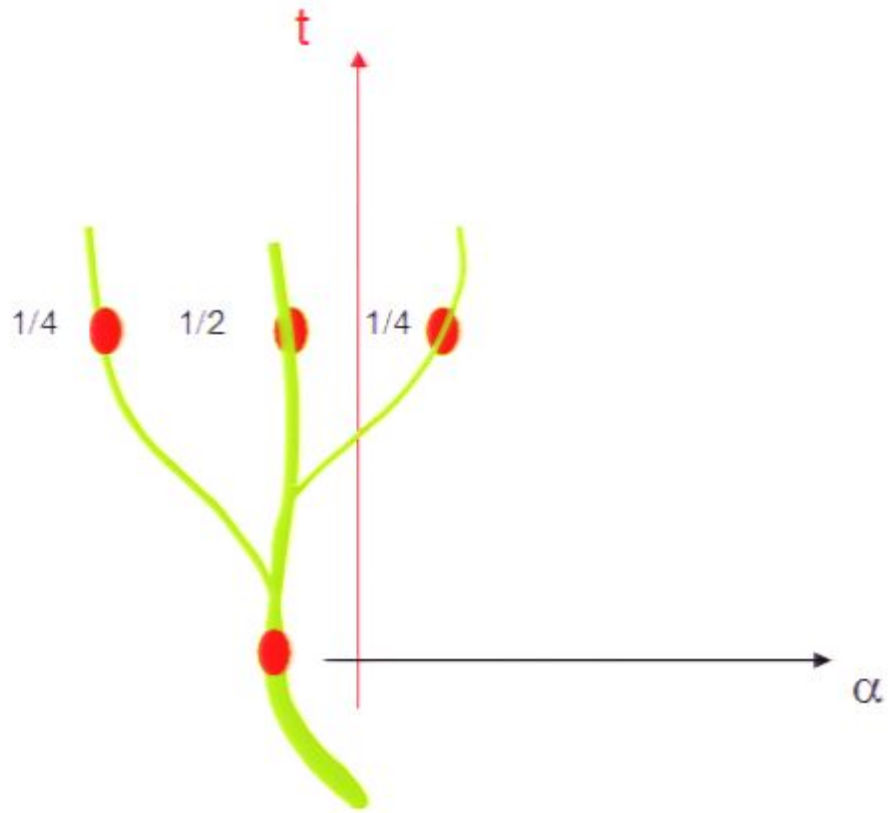
In a block universe…..



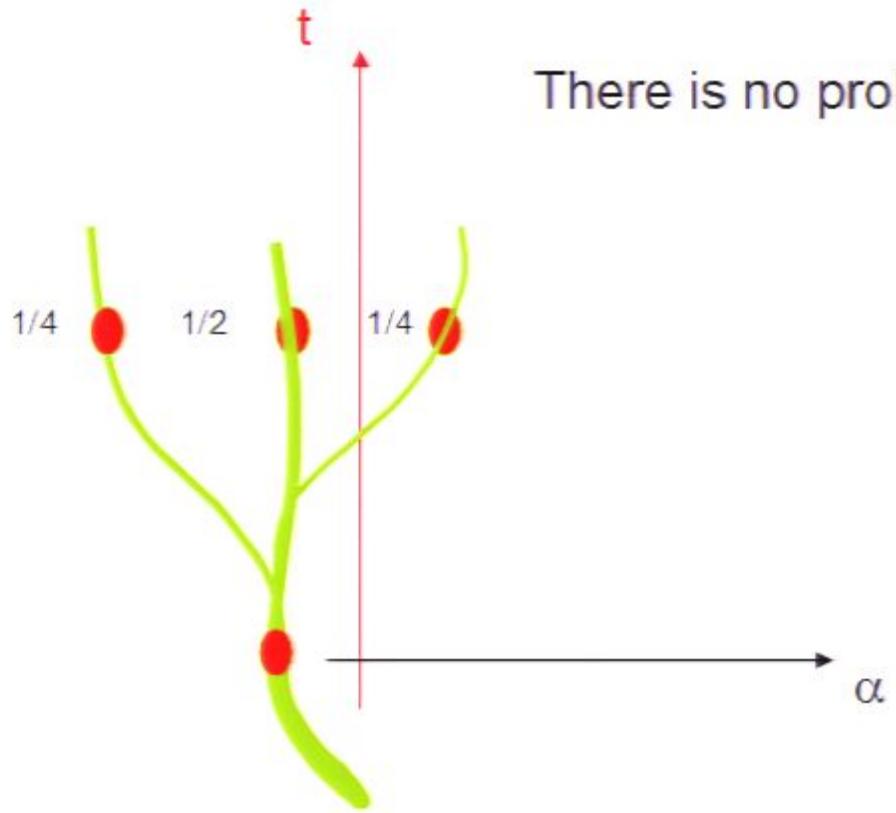
Change resides in the relations among events throughout your life-line

- The flow of time is….
- Becoming is…
- Free-will is…

In a branching universe….

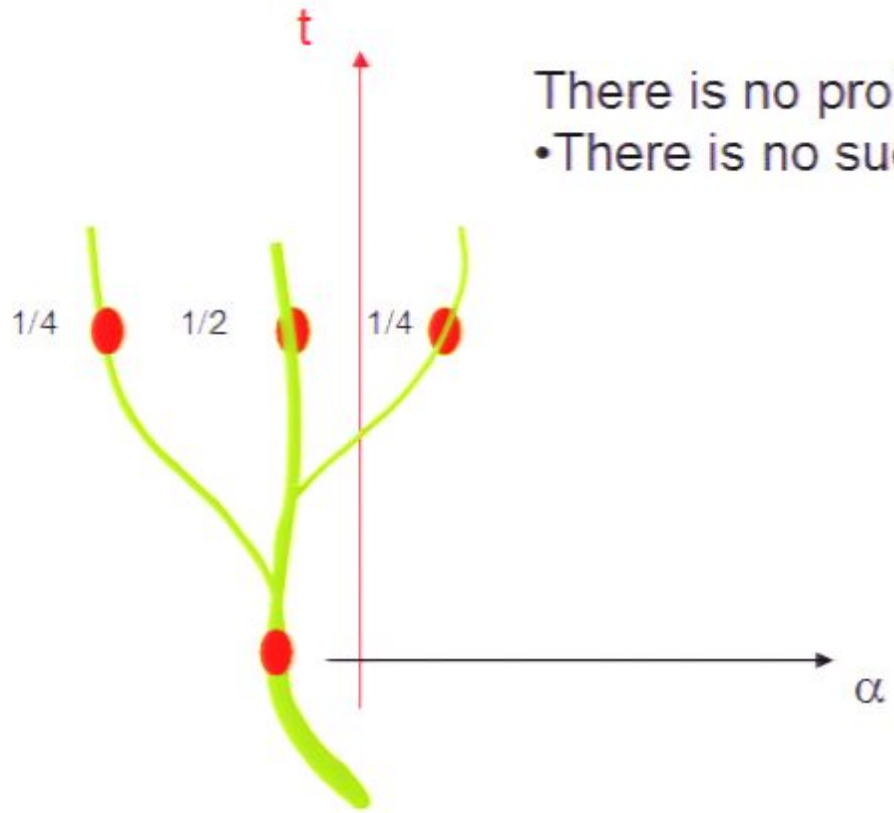


In a branching universe….



There is no probability

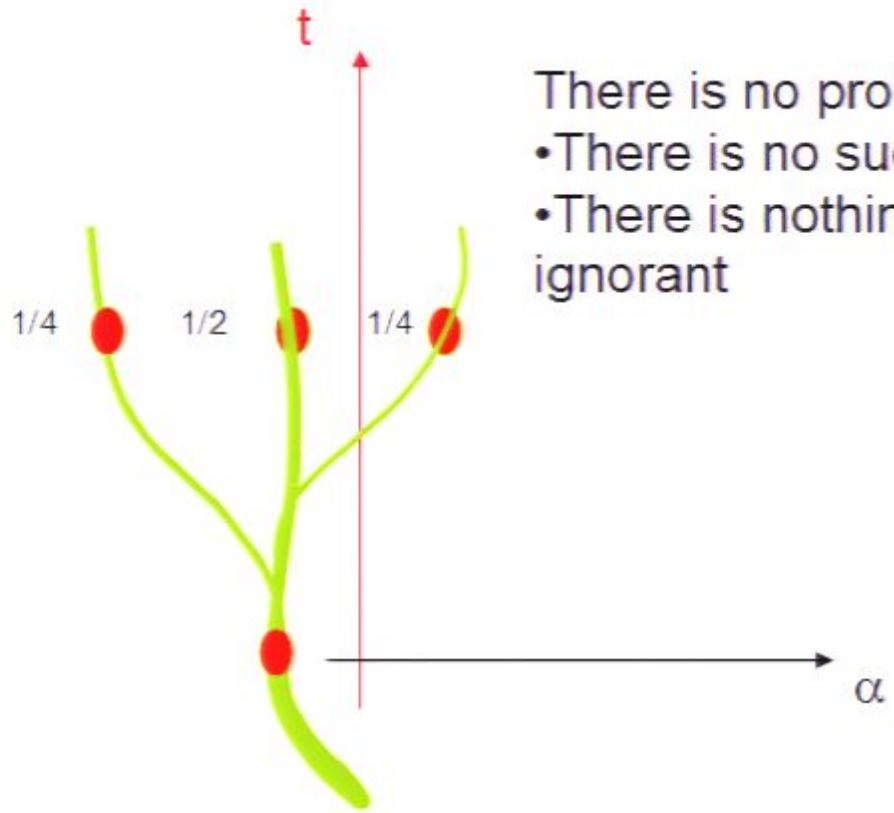
In a branching universe….



There is no probability

•There is no such thing as uncertainty

In a branching universe….

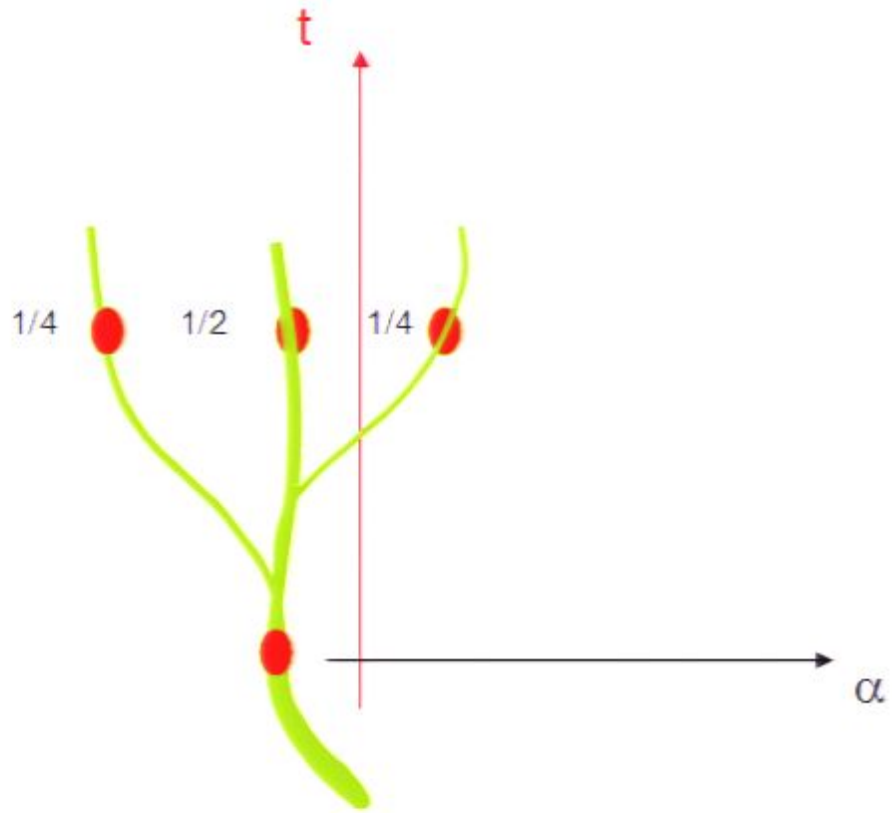


There is no probability

- There is no such thing as uncertainty
- There is nothing about which to be ignorant

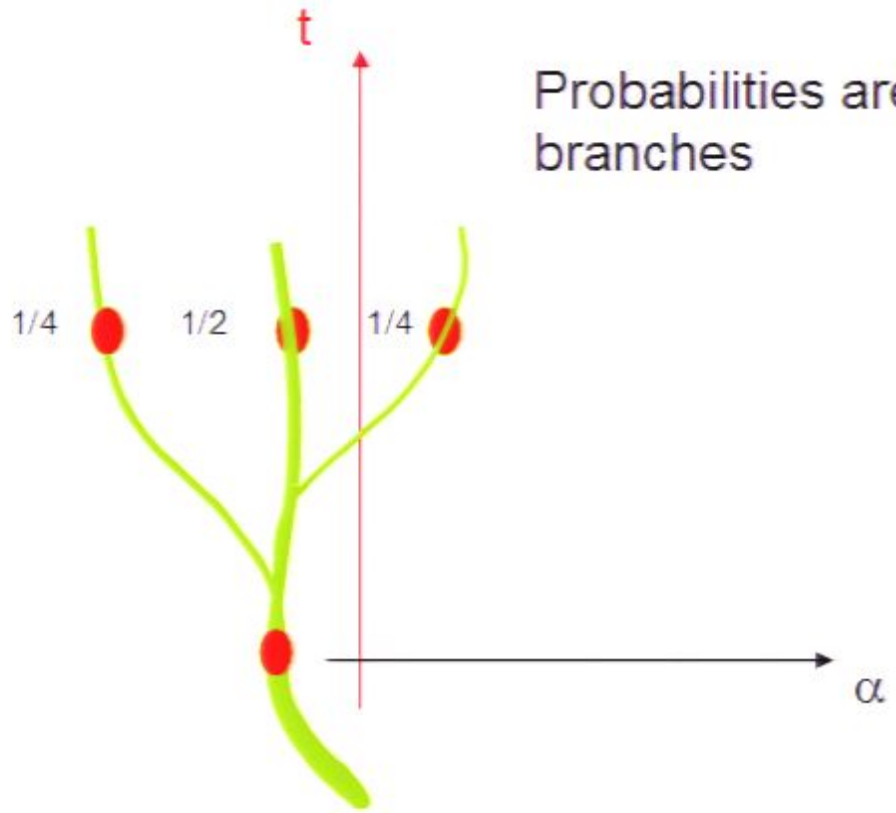
In a branching universe….

Alternatively:



In a branching universe….

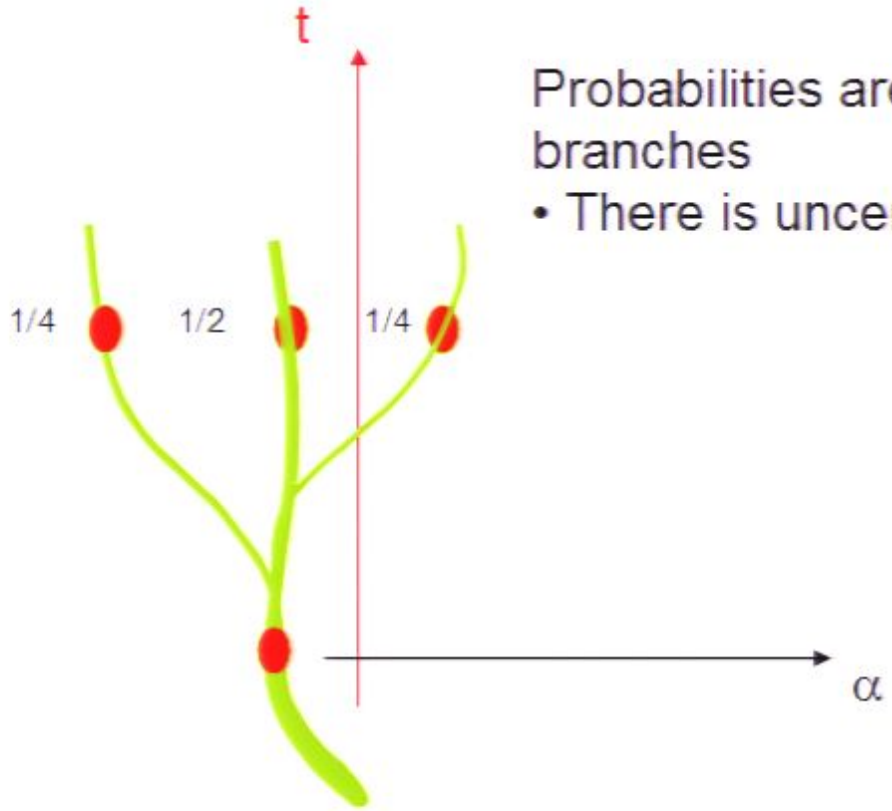
Alternatively:



Probabilities are relative weights of branches

In a branching universe….

Alternatively:

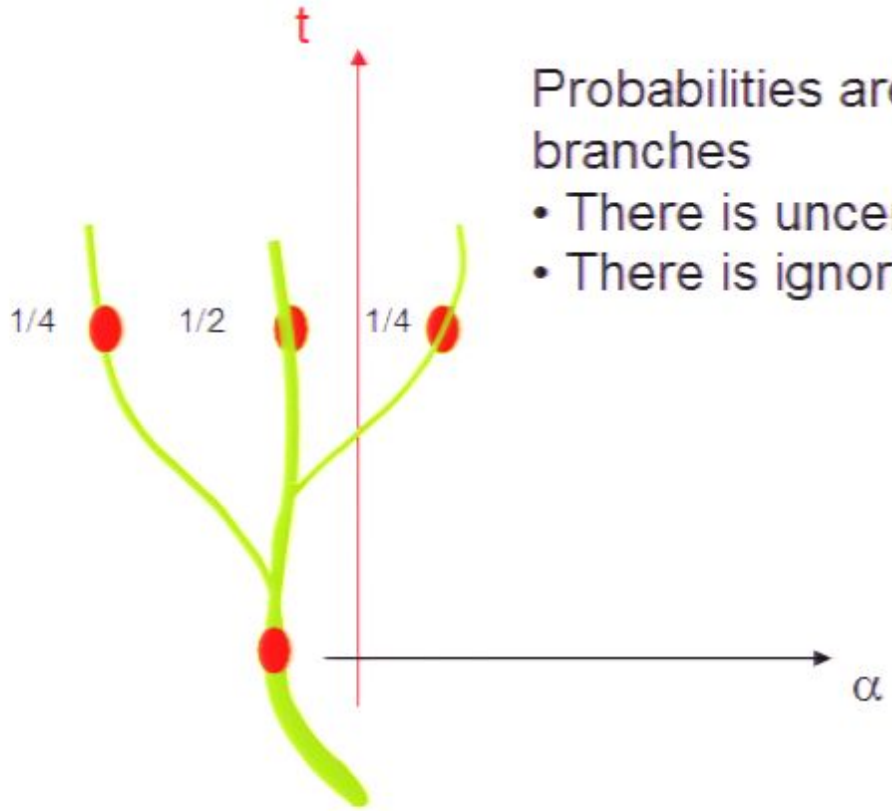


Probabilities are relative weights of branches

- There is uncertainty about…

In a branching universe….

Alternatively:

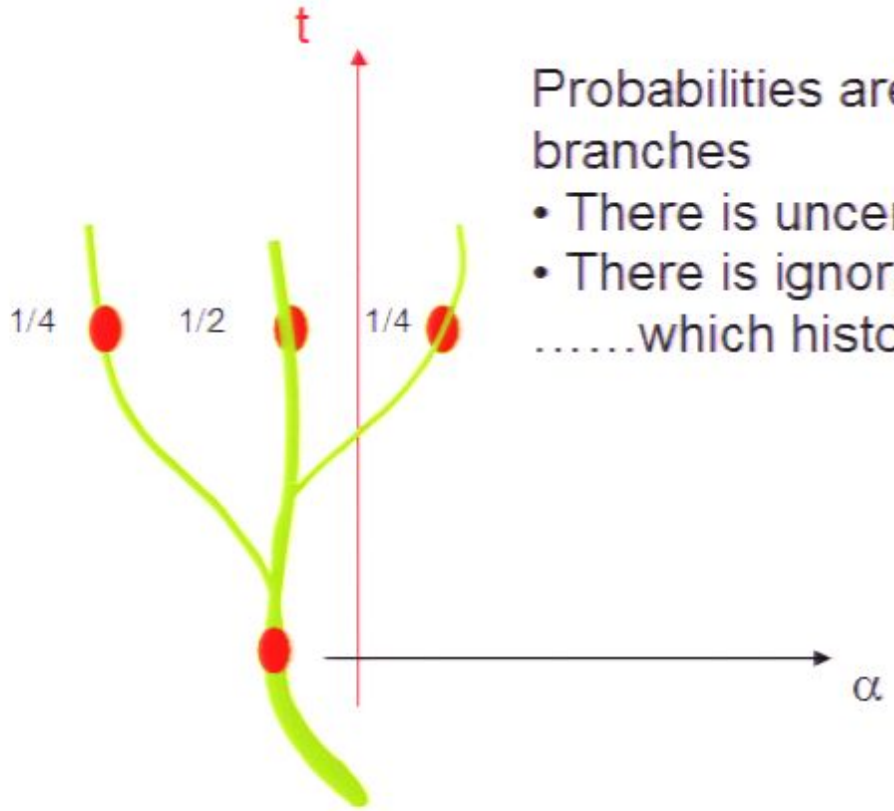


Probabilities are relative weights of branches

- There is uncertainty about…
- There is ignorance of….

In a branching universe….

Alternatively:

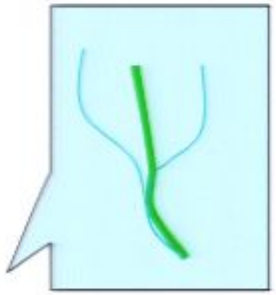


Probabilities are relative weights of branches

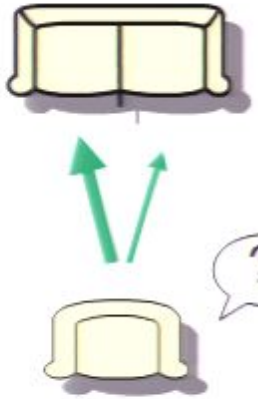
- There is uncertainty about…
- There is ignorance of….

……which history is one's own

suppose solved



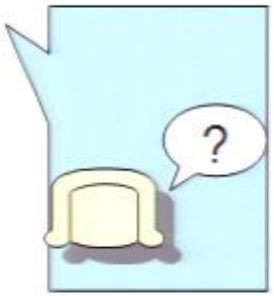
Incoherence problem



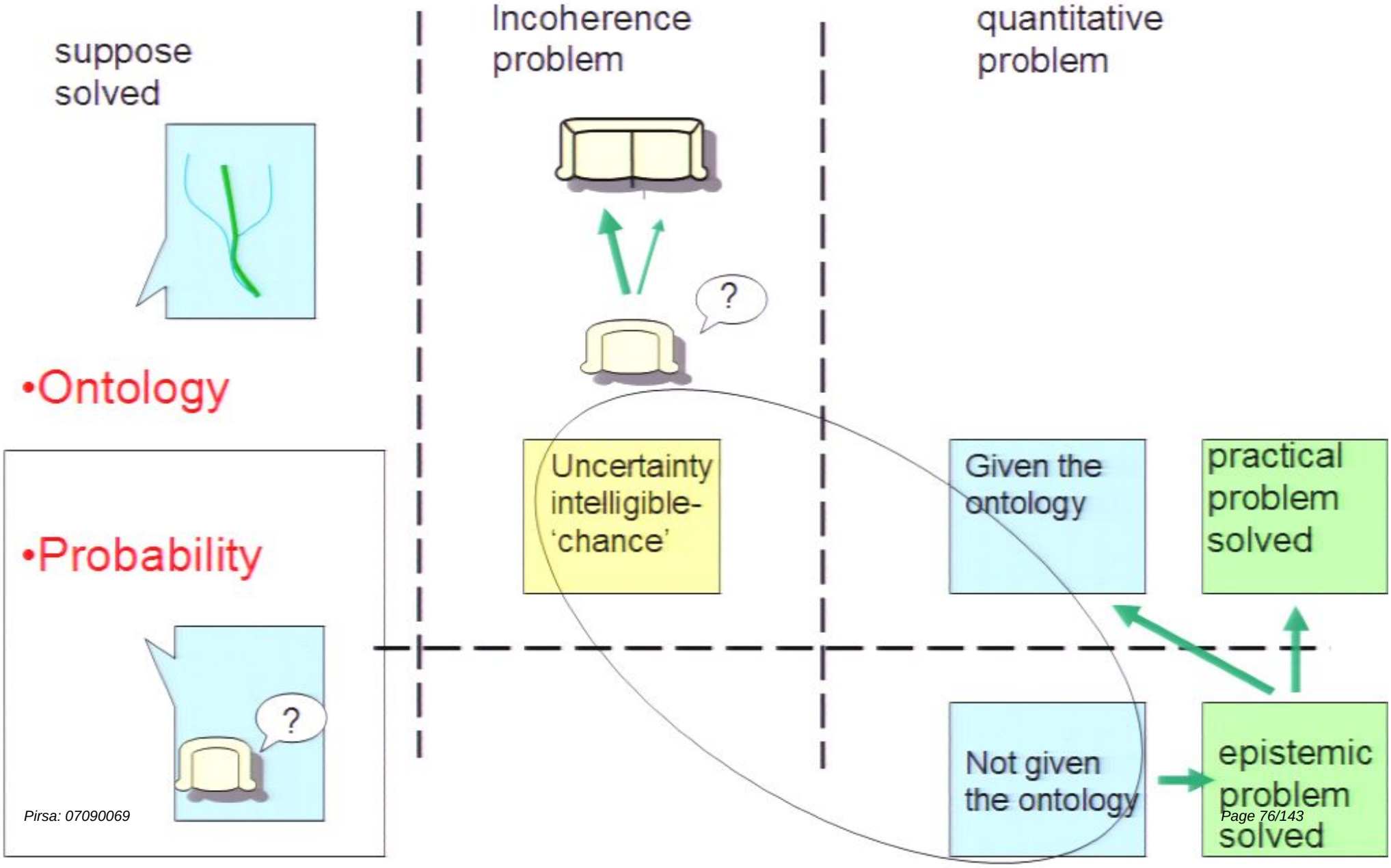
quantitative problem

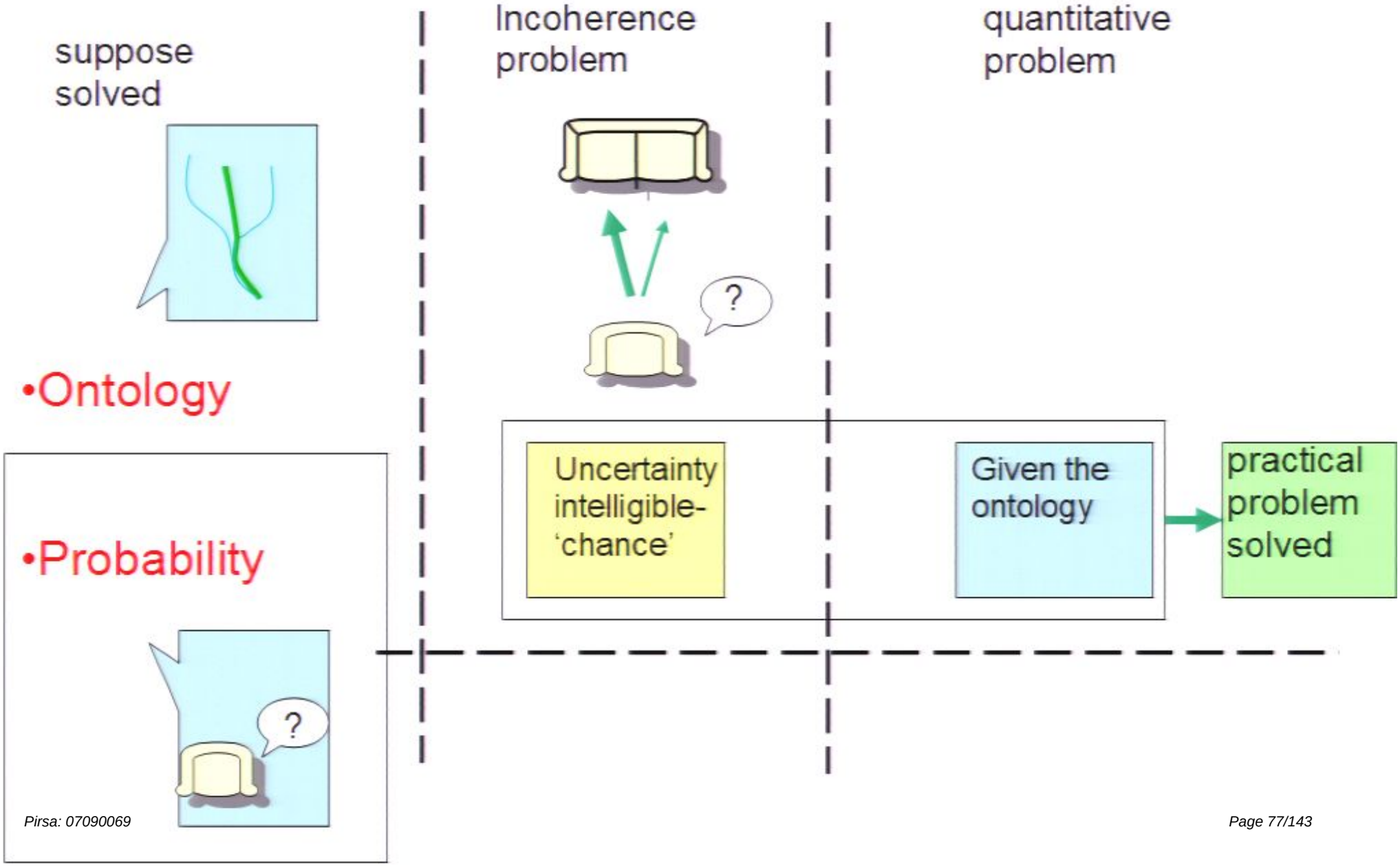
•Ontology

•Probability



Uncertainty intelligible- 'chance'


suppose
solved
Incoherence
problem
quantitative
problem
?
•Ontology
•Probability
Uncertainty
intelligible-
'chance'
Given the
ontology
practical
problem
solved
?
Not given
the ontology
epistemic
problem
solved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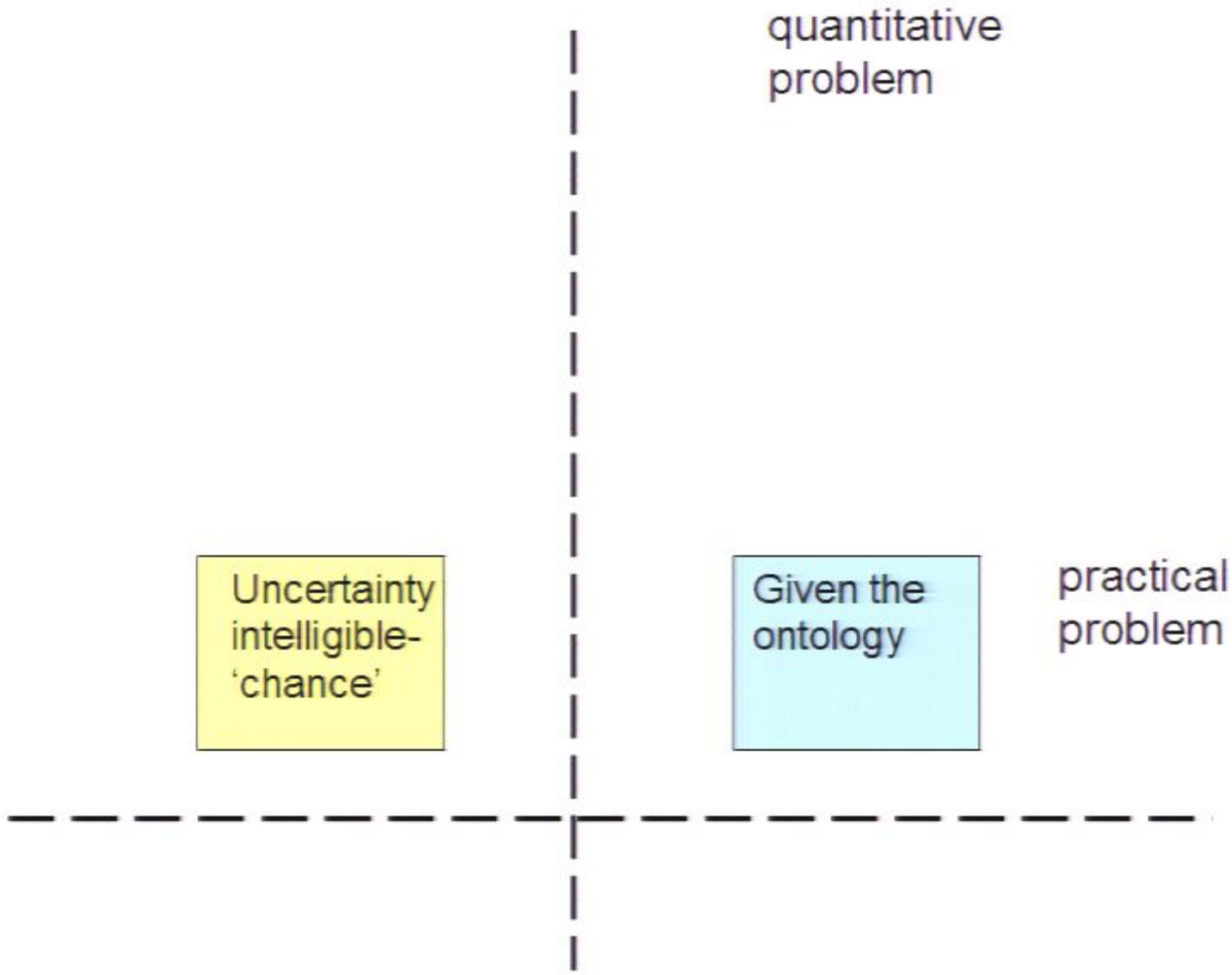
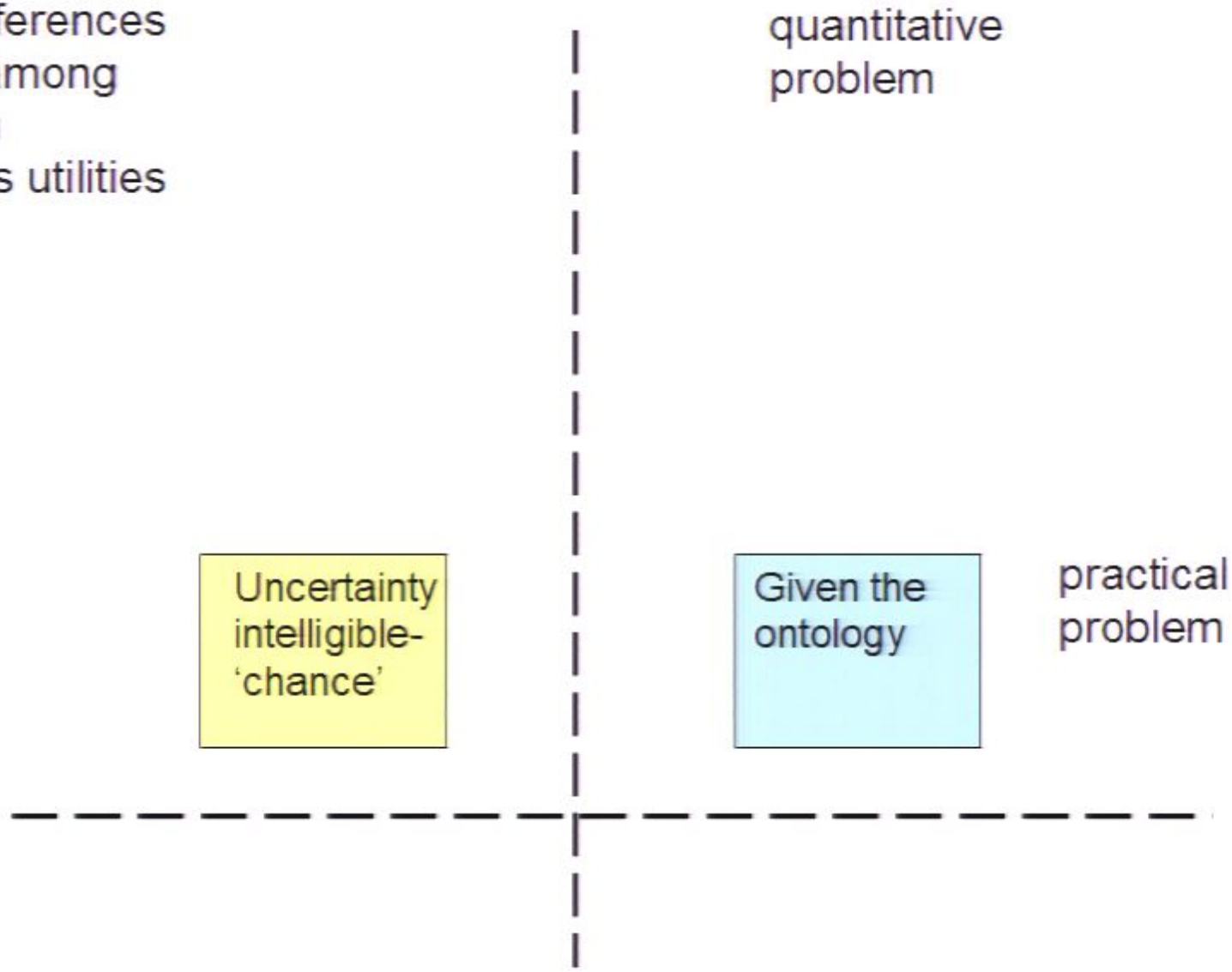
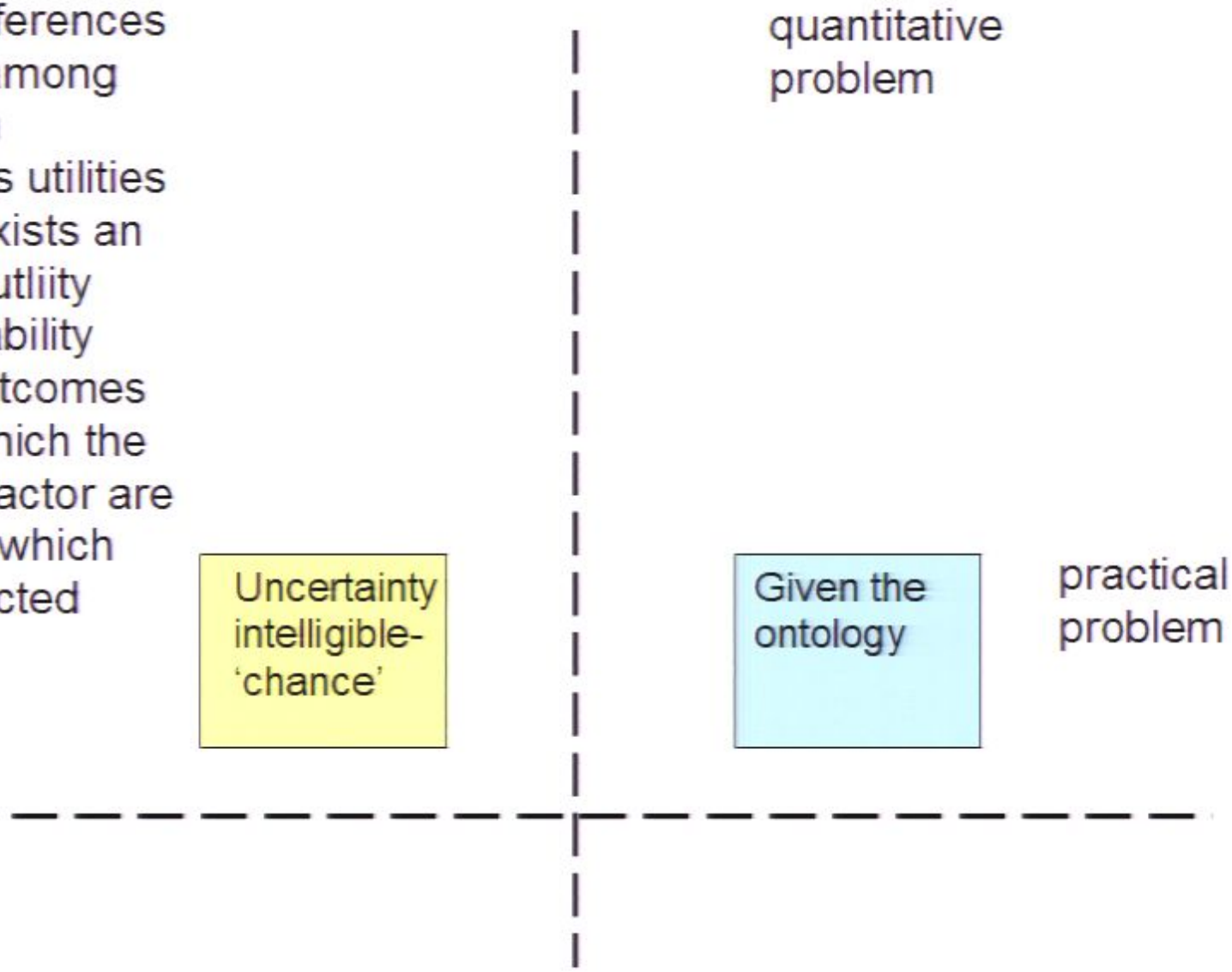

quantitative problem
Uncertainty intelligible- 'chance'
Given the ontology
practical problem

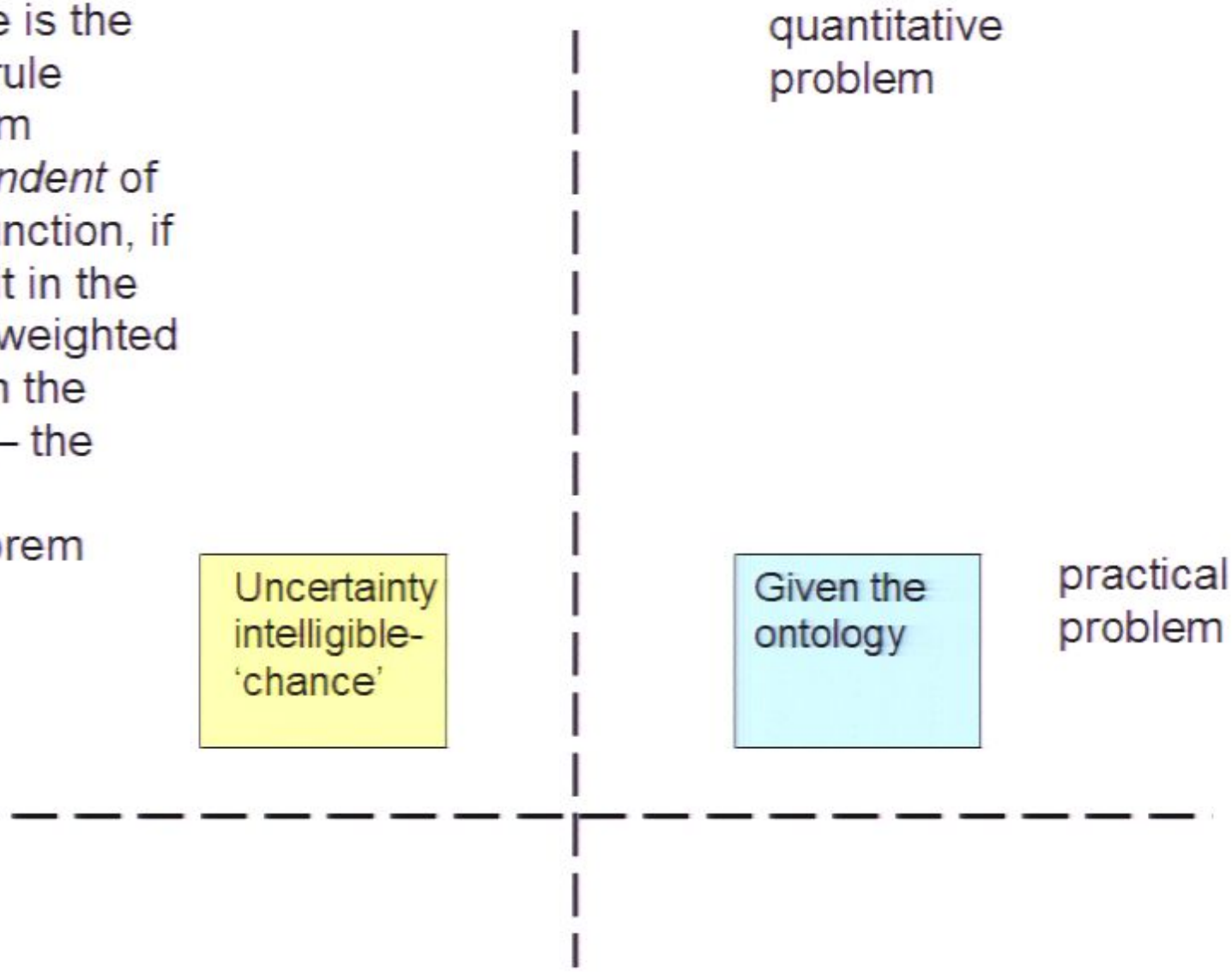
•Introduce axioms of rationality, to be satisfied in the rankings of preferences of a rational actor among quantum games, in accordance with his utilities



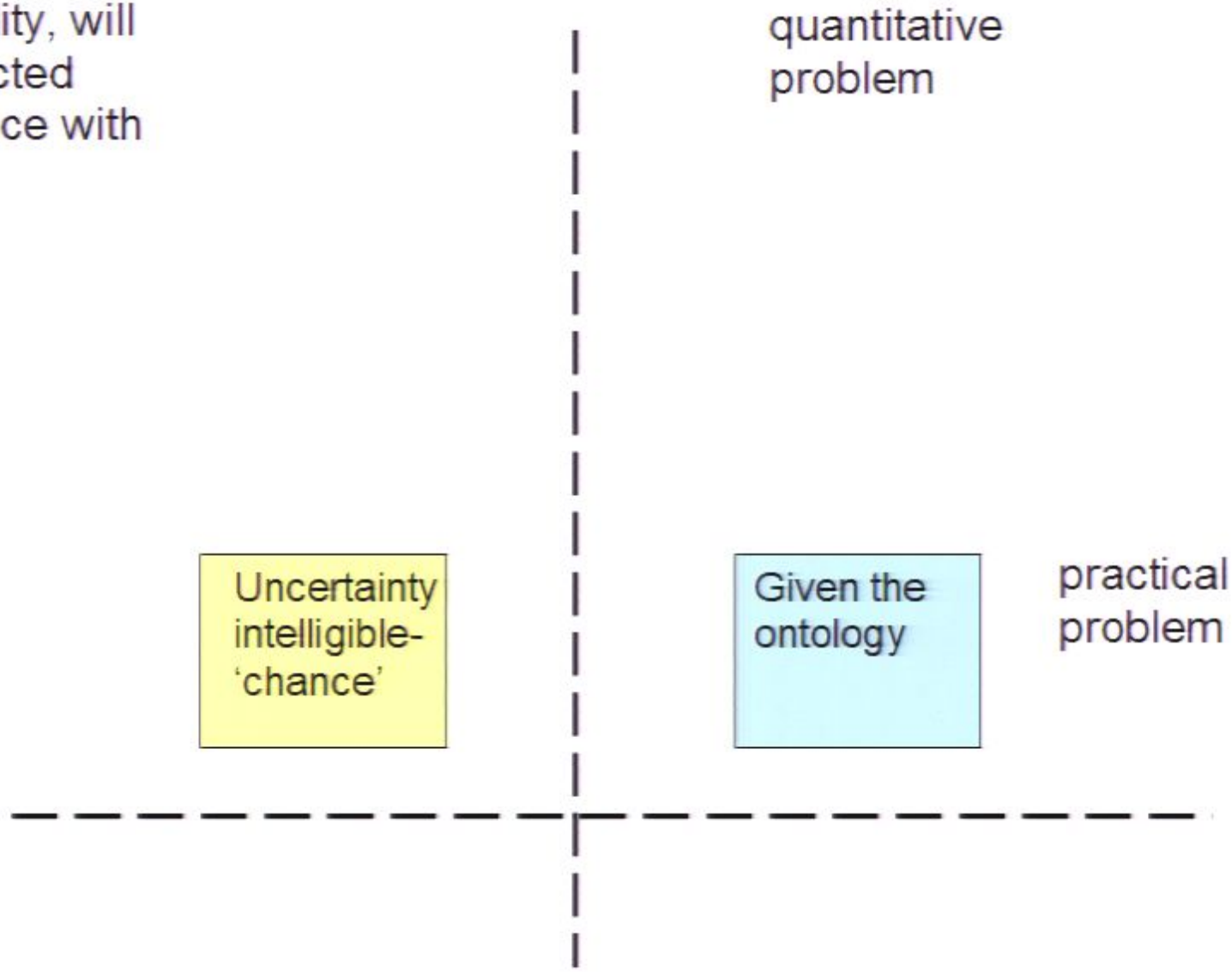
•Introduce axioms of rationality, to be satisfied in the rankings of preferences of a rational actor among quantum games, in accordance with his utilities
•Prove that there exists an essentially unique utliity function and probability distribution over outcomes of games, under which the preferences of the actor are the same as those which maximize the expected utilities.



•And prove (this is the essential point) that that probability measure is the same as the Born-rule measure of quantum mechanics, *independent* of the agent's utility function, if only it agrees with it in the case of EQUALLY weighted branches (i.e. given the 'equivalence rule') – the Deutsch-Wallace representation theorem



Conclude: if he obeys the equivalence rule, the agent, on pain of irrationality, will maximize his expected utilities in accordance with the Born rule.



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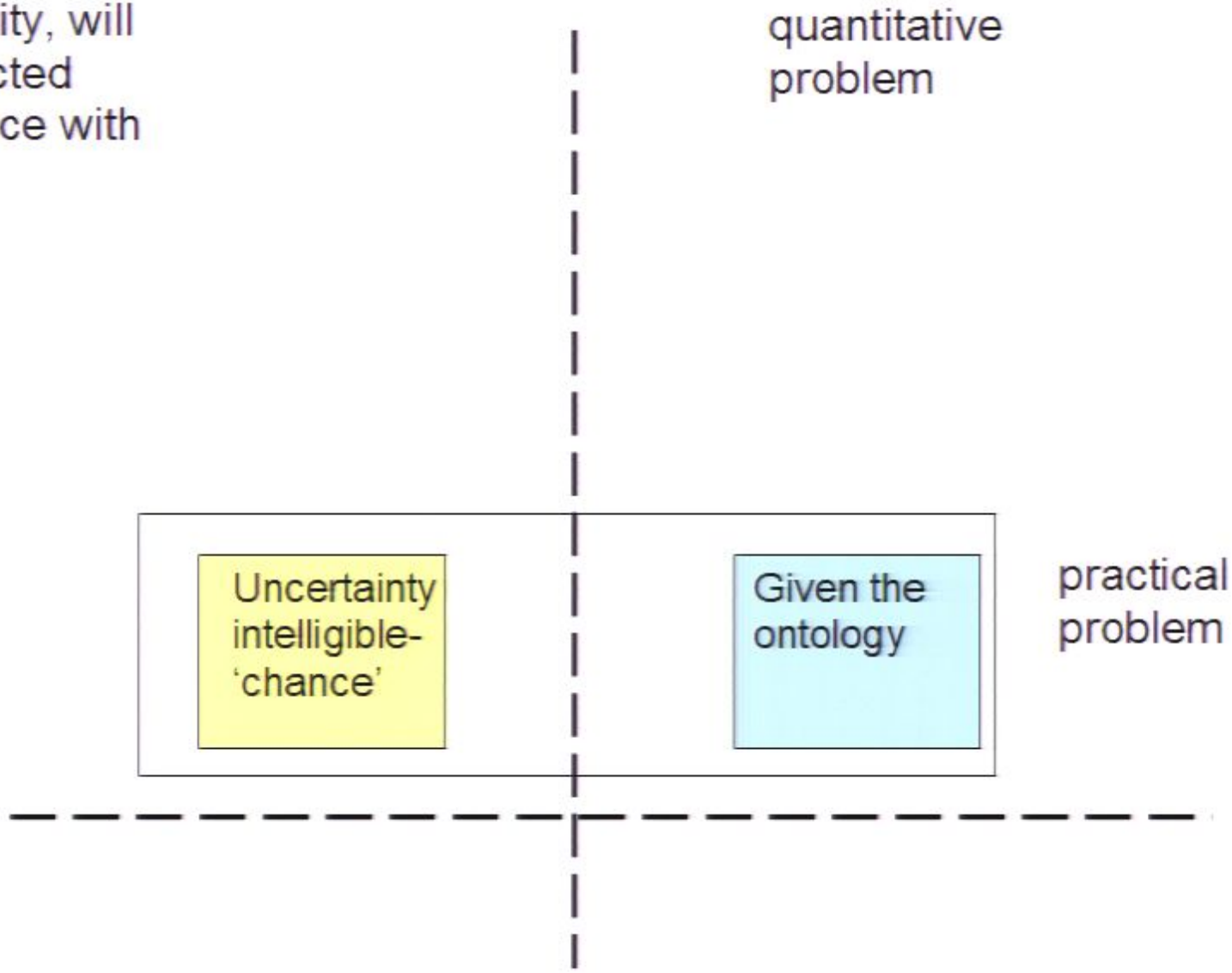

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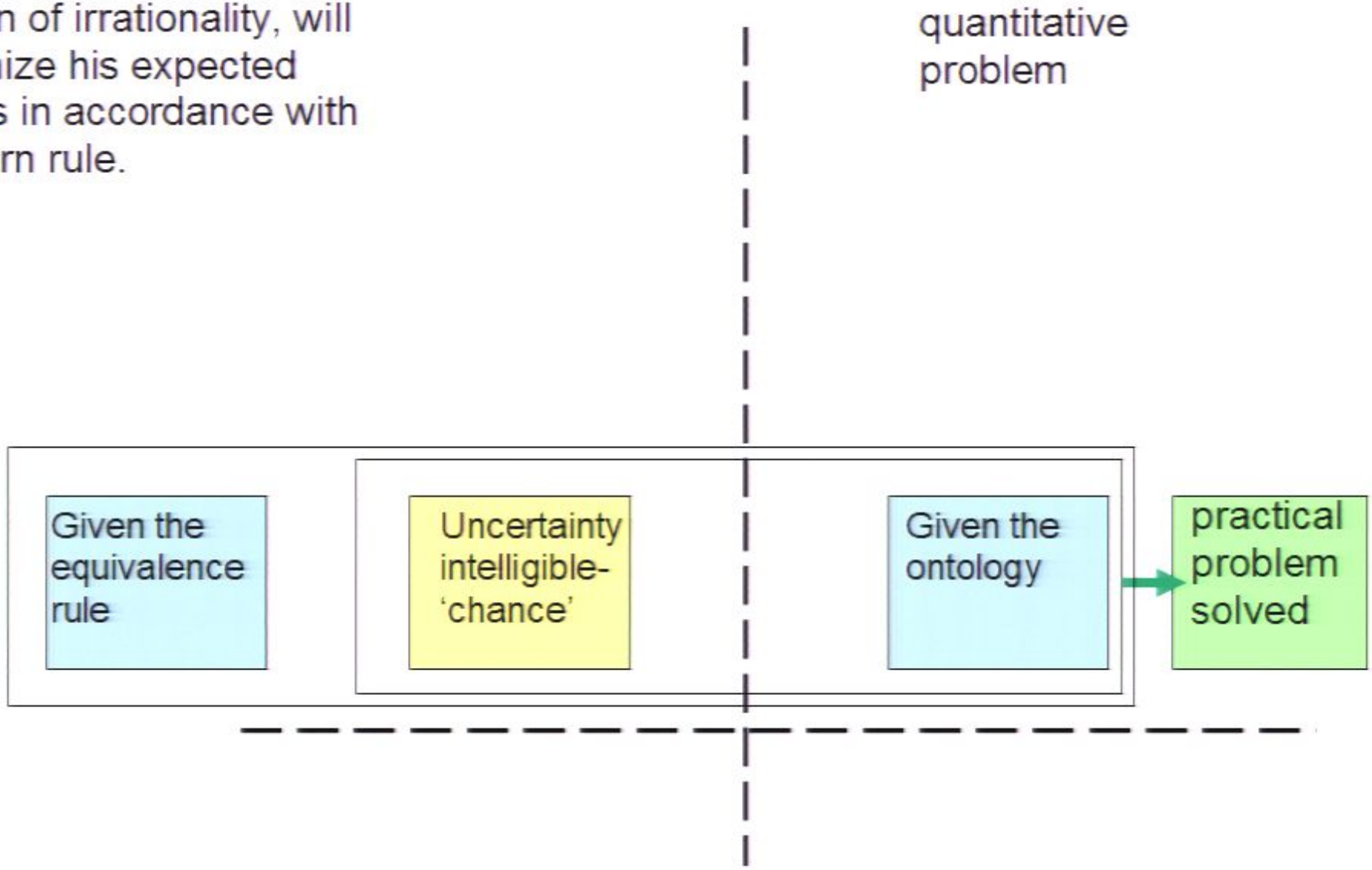


Why the equivalence rule?

Consider a Stern-Gerlach experiment, in which an atom is prepared in the superposion:

$$\phi = \frac{1}{\sqrt{2}}(\phi_+ + \phi_-)$$

Game 1: The agent receives the payoff iff the result is spin up
Game 2: The agent receives the payoff iff the results is spin downaw

game 1: $\psi \otimes \eta \otimes \phi \rightarrow \psi' \otimes \frac{1}{\sqrt{2}}(\eta^{\uparrow}_{+} \otimes \phi_+ + \eta^{\downarrow}_{-} \otimes \phi_-)$

game 2: $\psi \otimes \eta \otimes \phi \rightarrow \psi'' \otimes \frac{1}{\sqrt{2}}(\eta^{\downarrow}_{+} \otimes \phi_+ + \eta^{\uparrow}_{-} \otimes \phi_-)$

where ψ', ψ'' differ in inessential ways that the agent doesn't care about

Why the equivalence rule?

$\eta^{r}_{+} = |\alpha\rangle\,|\text{Reward}\rangle$ $\qquad$ $\eta^{r}_{-} = |\beta\rangle\,|\text{Reward}\rangle$

$\eta^{\neg r}_{+} = |\alpha\rangle\,|\text{No Reward}\rangle$ $\qquad$ $\eta^{\neg r}_{-} = |\beta\rangle\,|\text{No Reward}\rangle$

So the choice is between

Game 1: $\frac{1}{\sqrt{2}}\left(|\alpha\rangle\,|\text{Reward}\rangle + |\beta\rangle\,|\text{No reward}\rangle\right)$

Game 2: $\frac{1}{\sqrt{2}}\left(|\alpha\rangle\,|\text{No Reward}\rangle + |\beta\rangle\,|\text{Reward}\rangle\right)$

Why the equivalence rule?

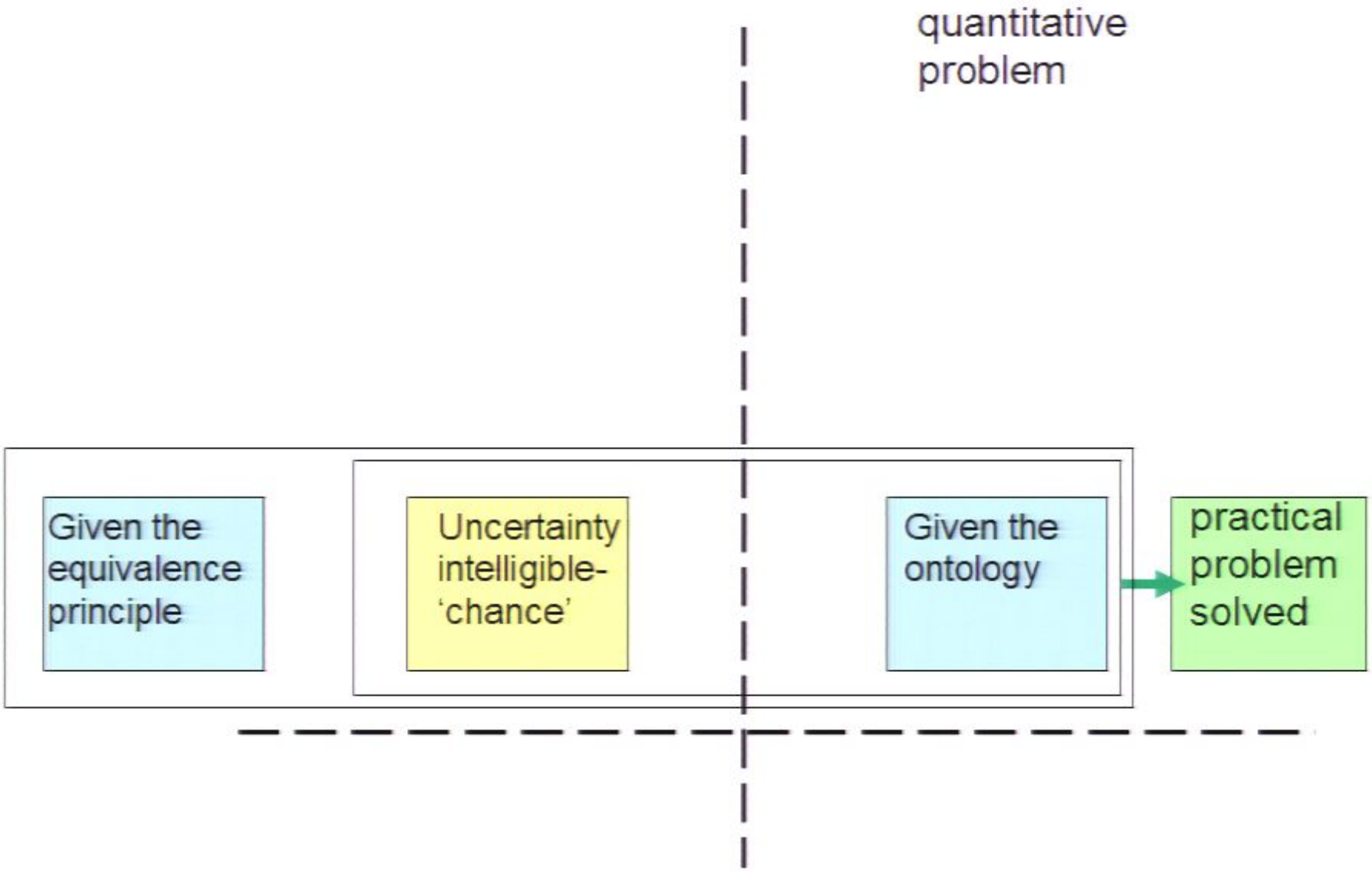
But the agent doesn't care about $|\alpha\rangle$ and $|\beta\rangle$!

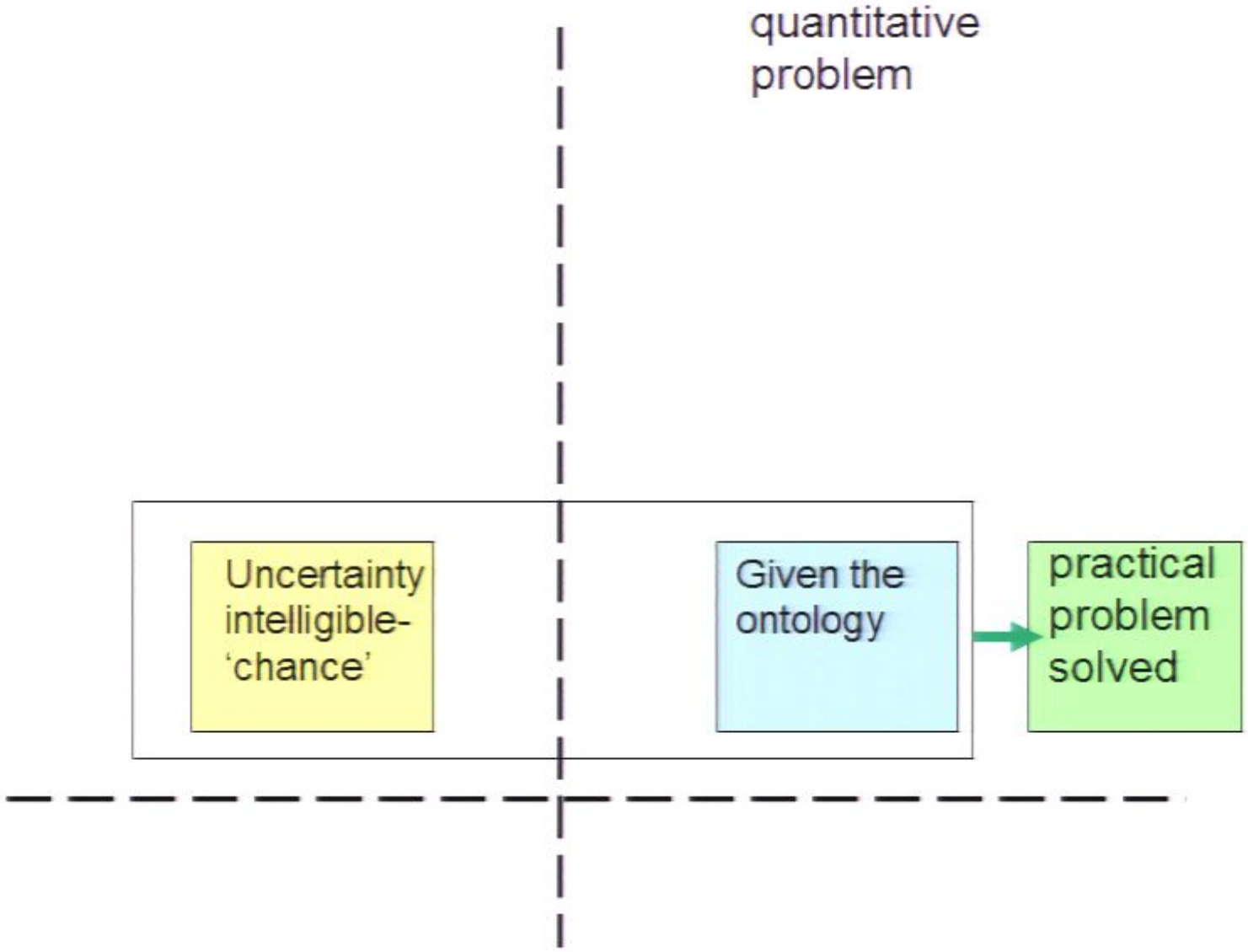
So let the numerical value displayed be erased

The result is:

Game 1: $\frac{1}{\sqrt{2}}\left(|\text{erased}\rangle|\text{reward}\rangle + |\text{erased}\rangle|\text{no reward}\rangle\right)$

Game 2: $\frac{1}{\sqrt{2}}\left(|\text{erased}\rangle|\text{No reward}\rangle + |\text{erased}\rangle|\text{Reward}\rangle\right)$


quantitative problem
Given the equivalence principle
Uncertainty intelligible- 'chance'
Given the ontology
practical problem solved


quantitative problem
Uncertainty intelligible- 'chance'
Given the ontology
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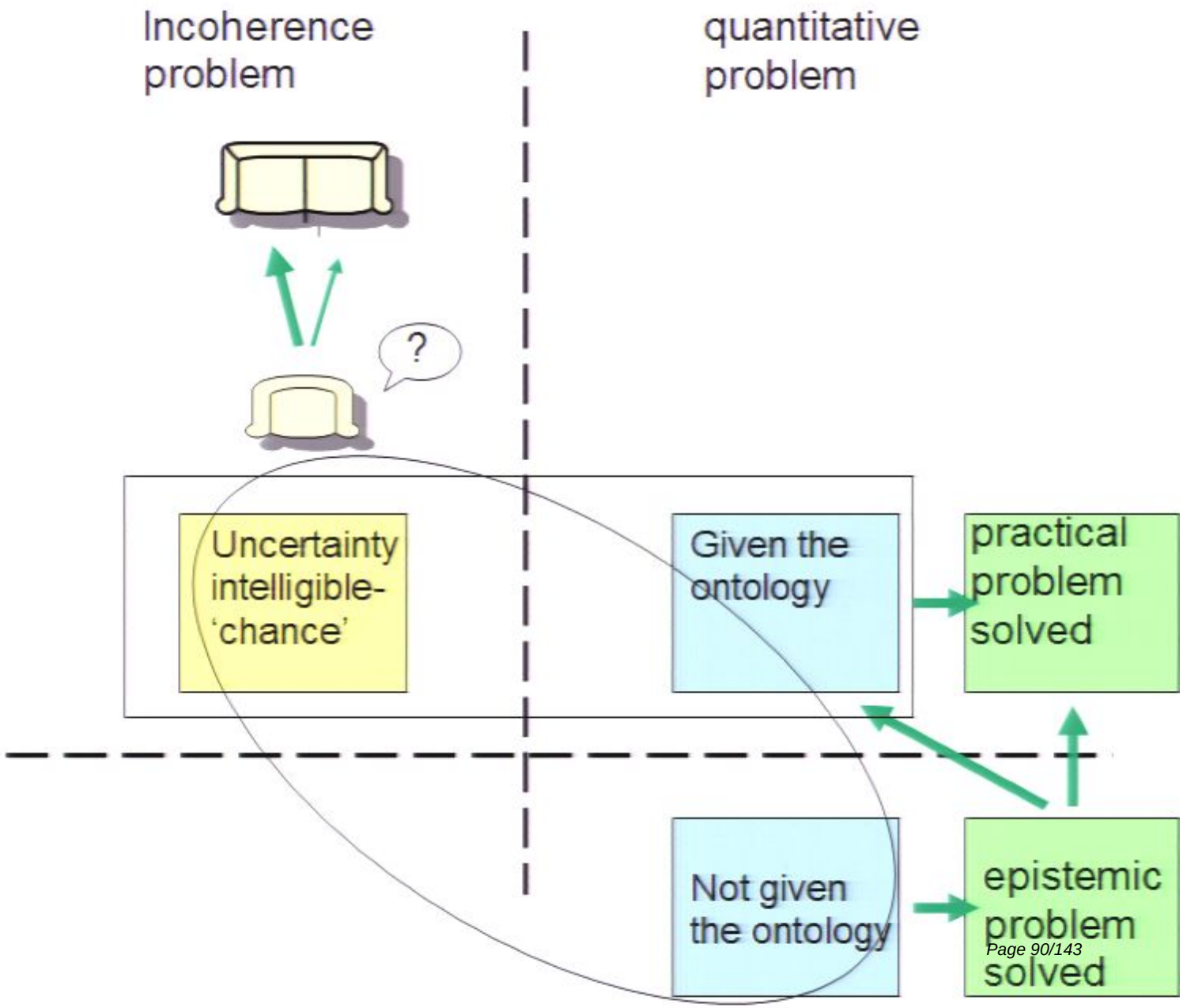
Incoherence problem
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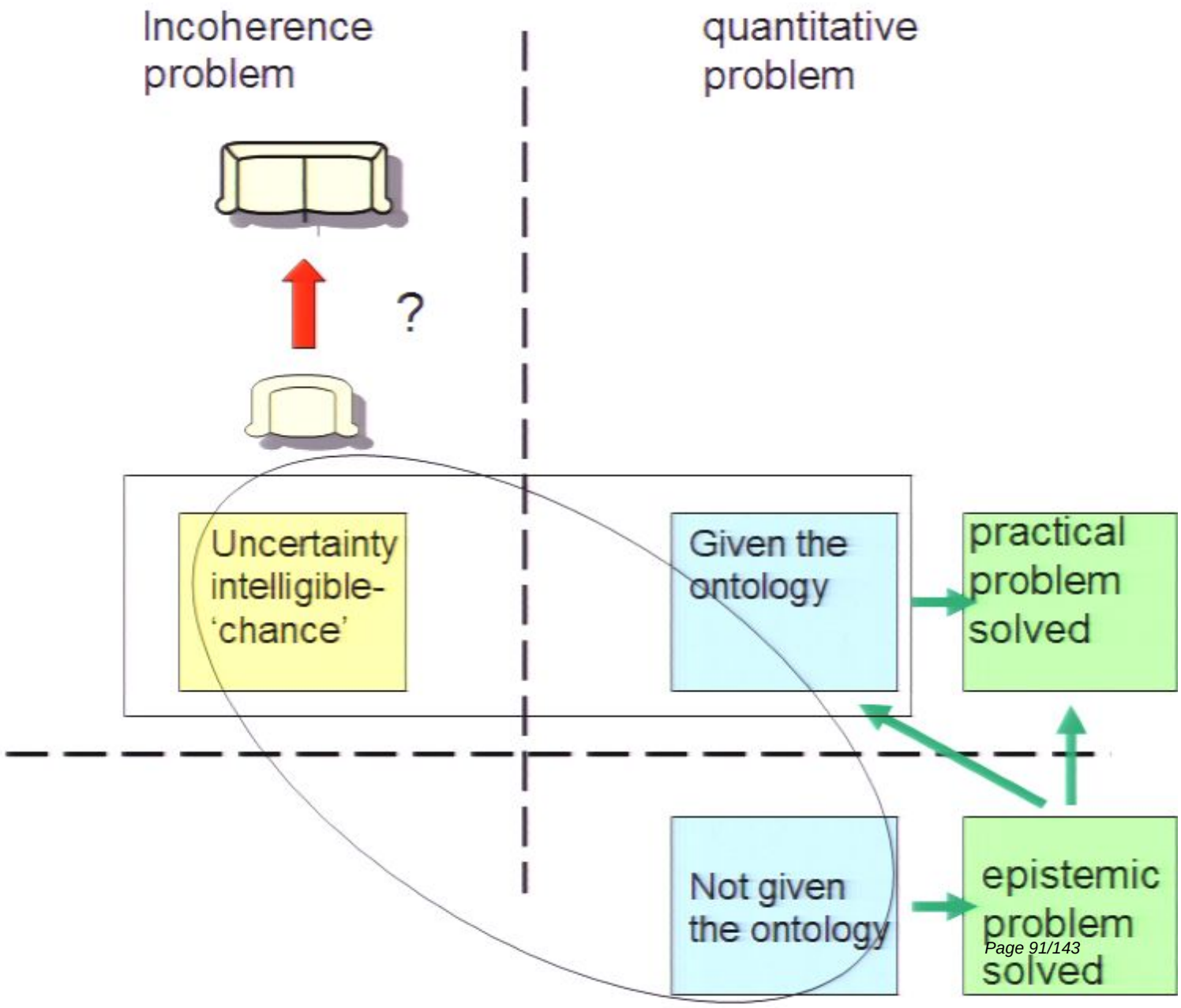
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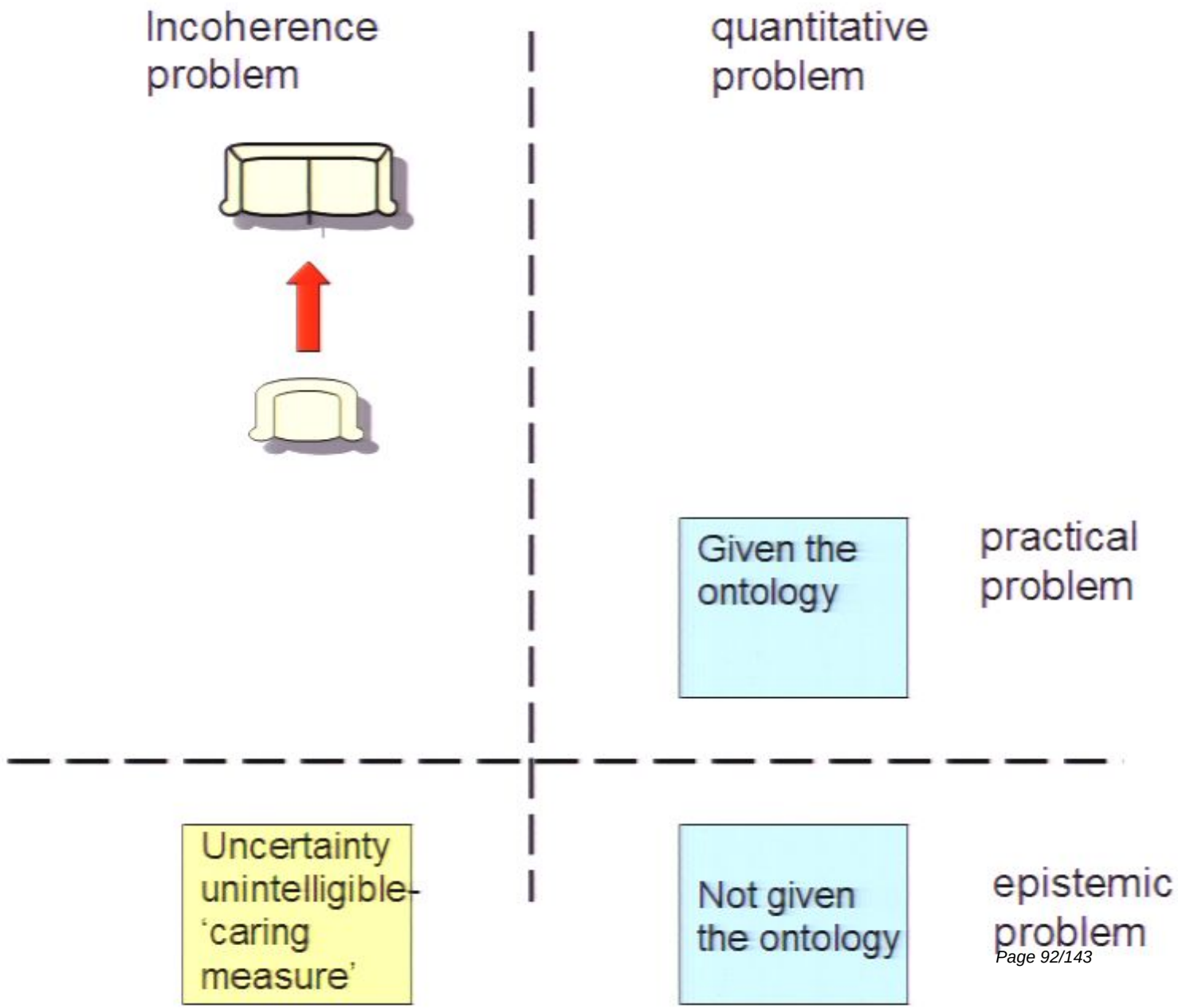
Incoherence problem
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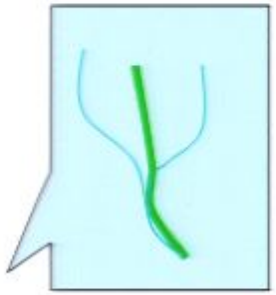
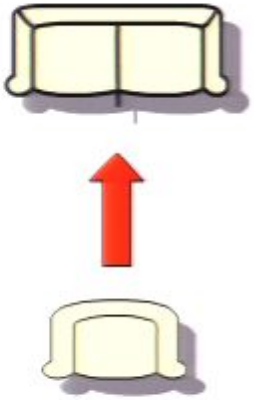
epistemic problem

suppose solved



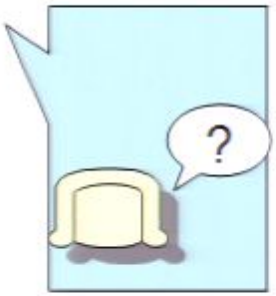
Incoherence problem



quantitative problem

•Ontology

•Probability



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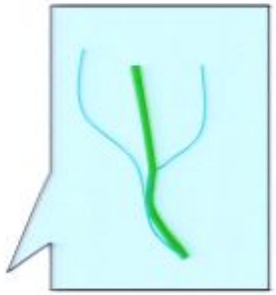

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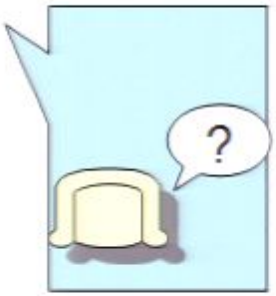

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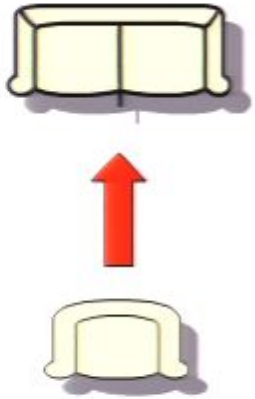

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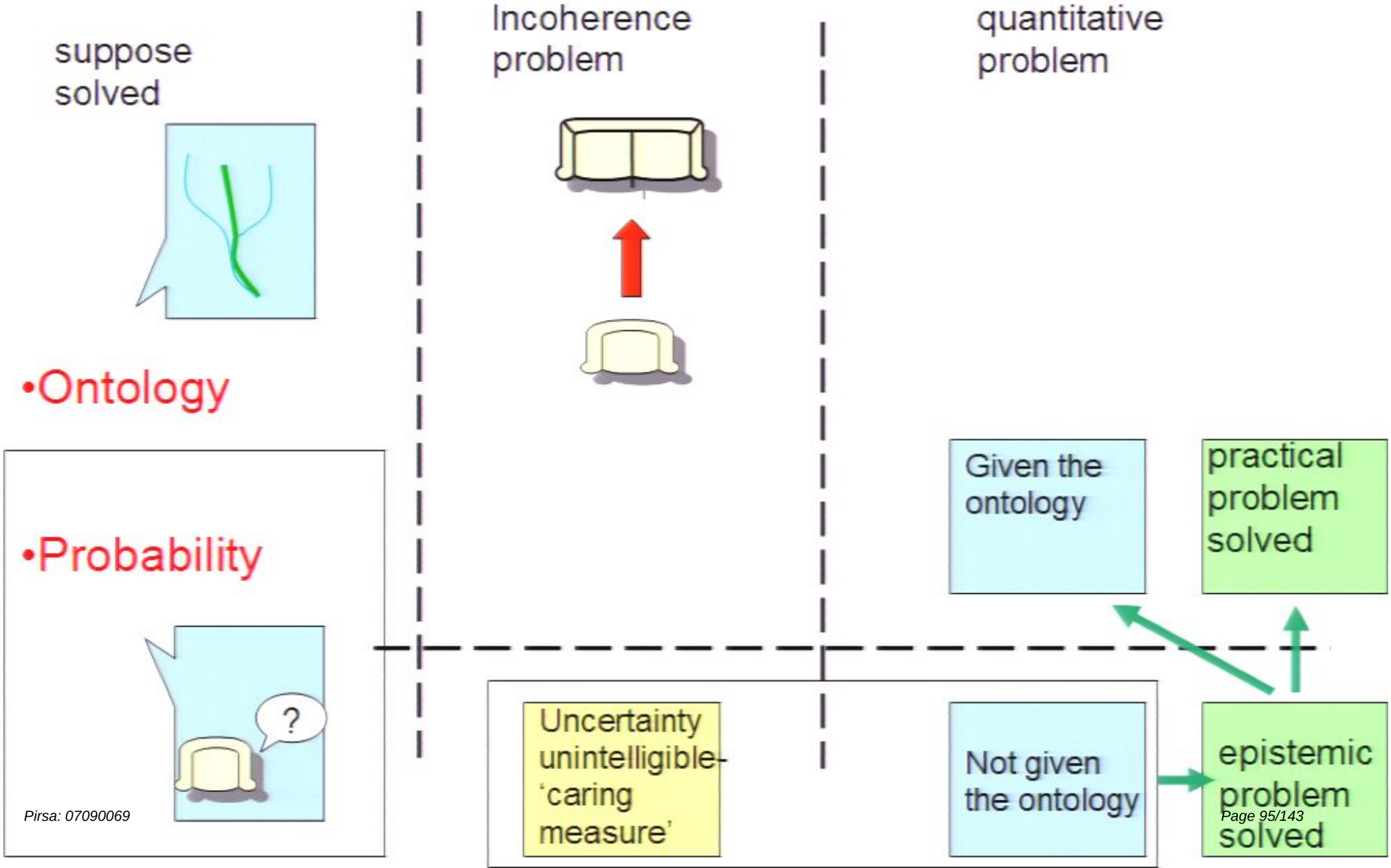
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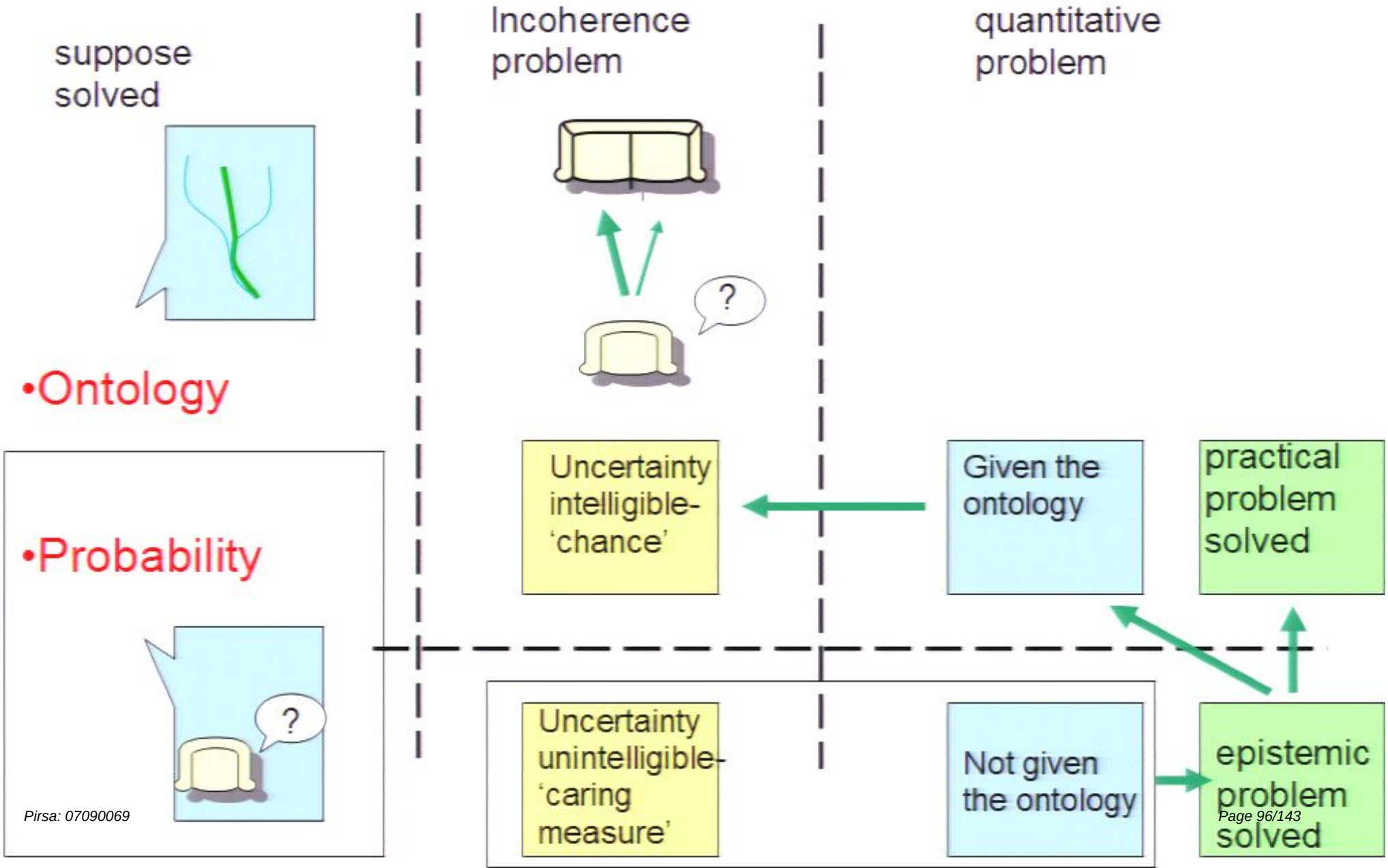
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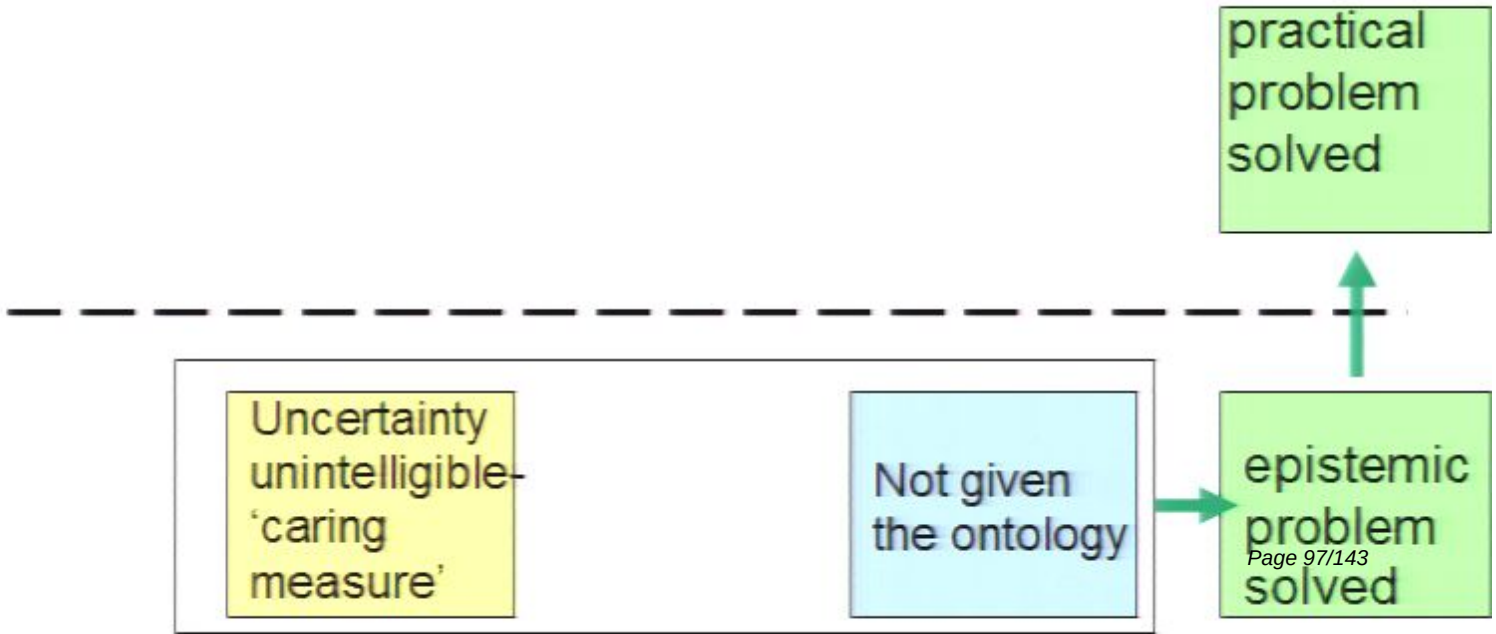
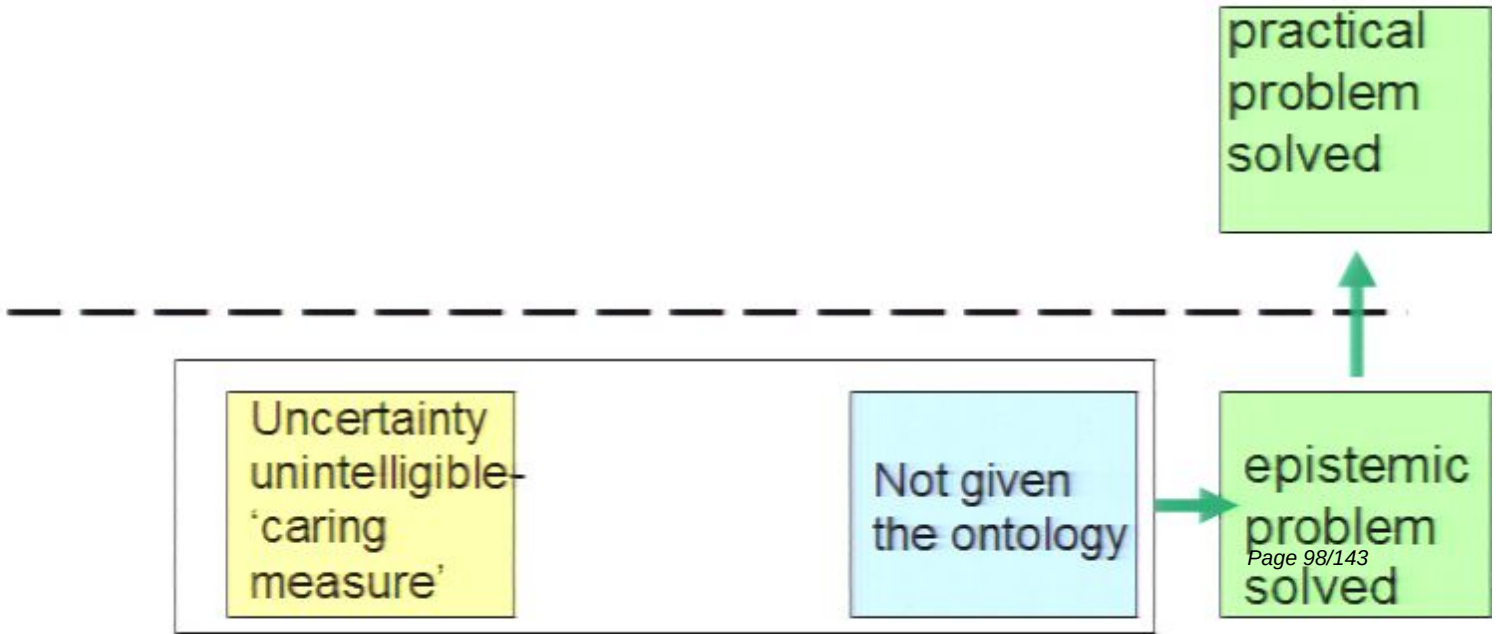


•Introduce axioms of rationality as before

•to be satisfied in the rankings of preferences of a rational actor among quantum games

quantitative problem

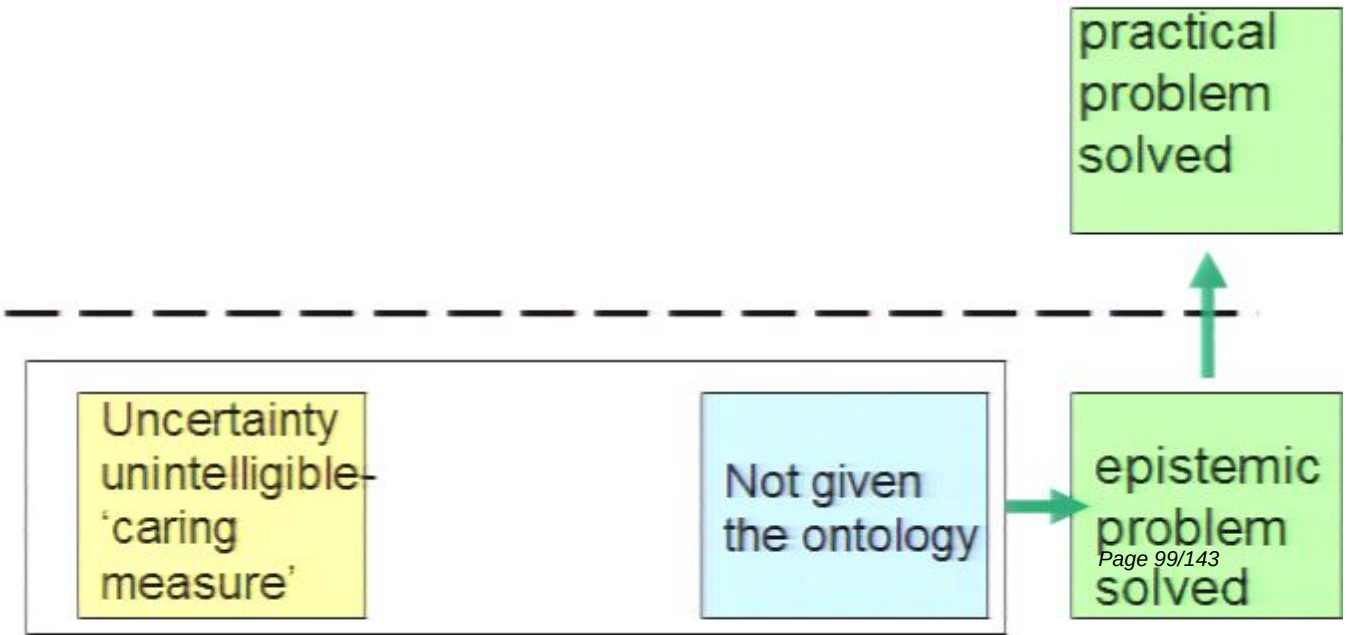


•Introduce axioms of rationality (Savage)

•to be satisfied in the rankings of preferences of a rational actor among quantum games.

•Prove there exists an essentially unique utility function and probability distribution over outcomes of games, under which the preferences of the actor are the same as those which maximize the expected utilities.

quantitative problem



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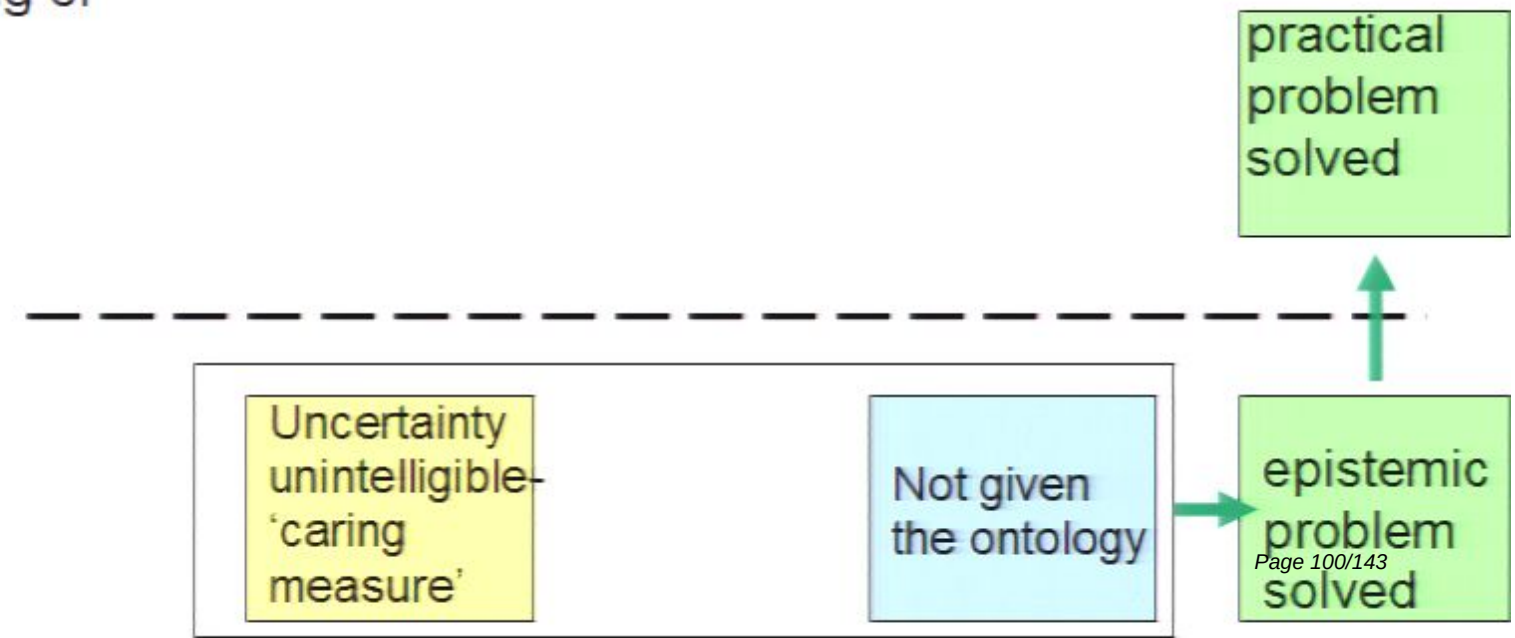
•in accordance with which she acts as if employing standard Bayesian updating of priors, on given evidence.

quantitative problem



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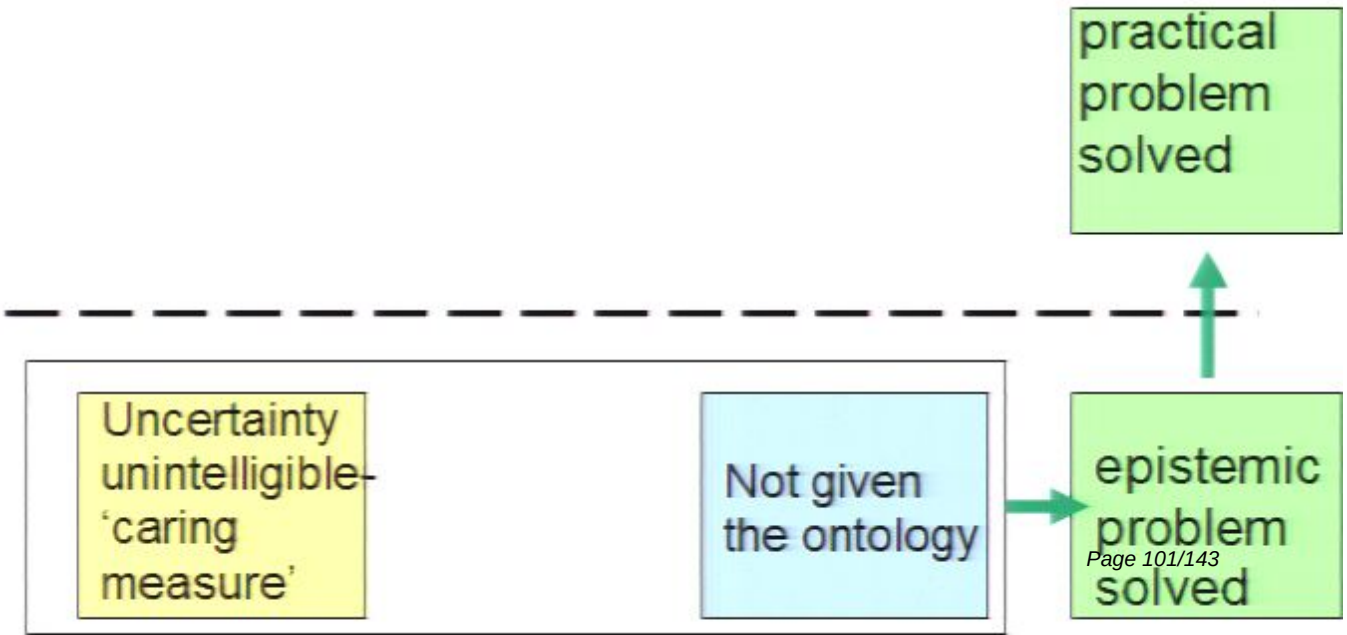

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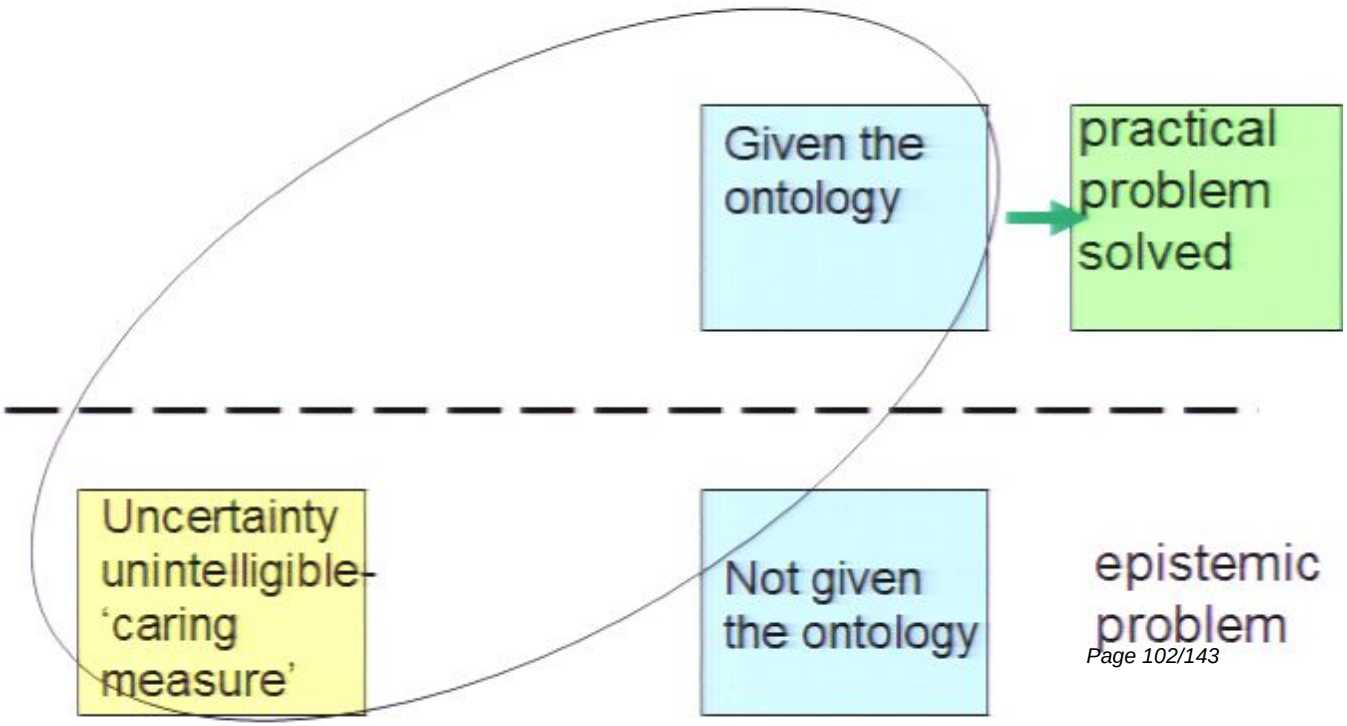
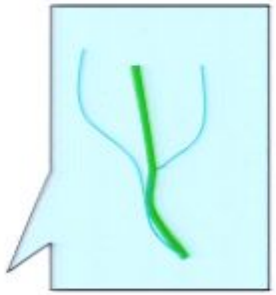


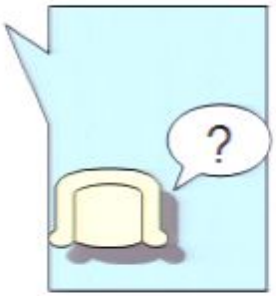
suppose solved



Incoherence problem

quantitative problem

- Ontology
- Probability



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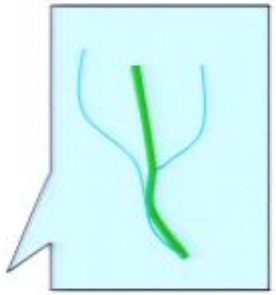

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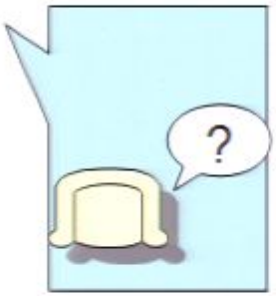
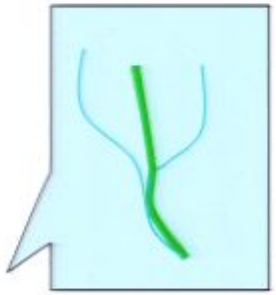


Incoherence problem

quantitative problem

What's the wave-function a function of?



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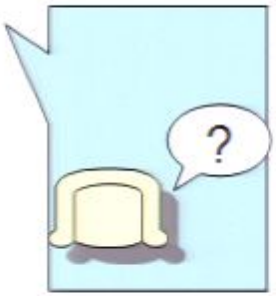

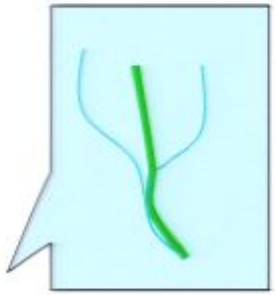

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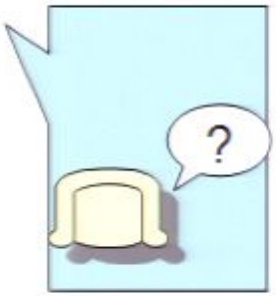


Incoherence problem

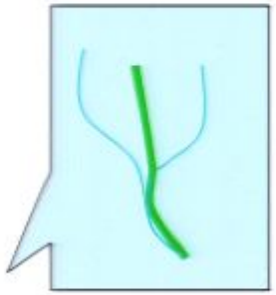
What's the wave-function a function of?

Is configuration space real, in the way that spacetime is real?

quantitative problem

To solve the measurement problem…

Universality • no mention of measurement • no special interpretative assumption or additional eqs



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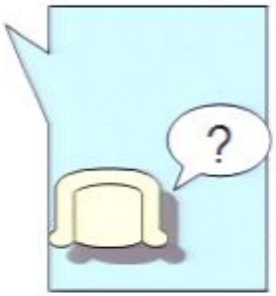

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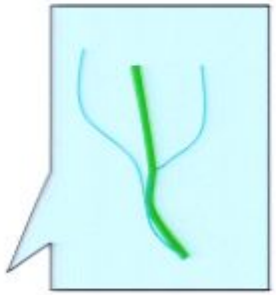

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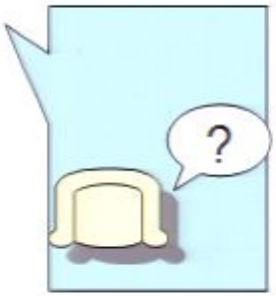

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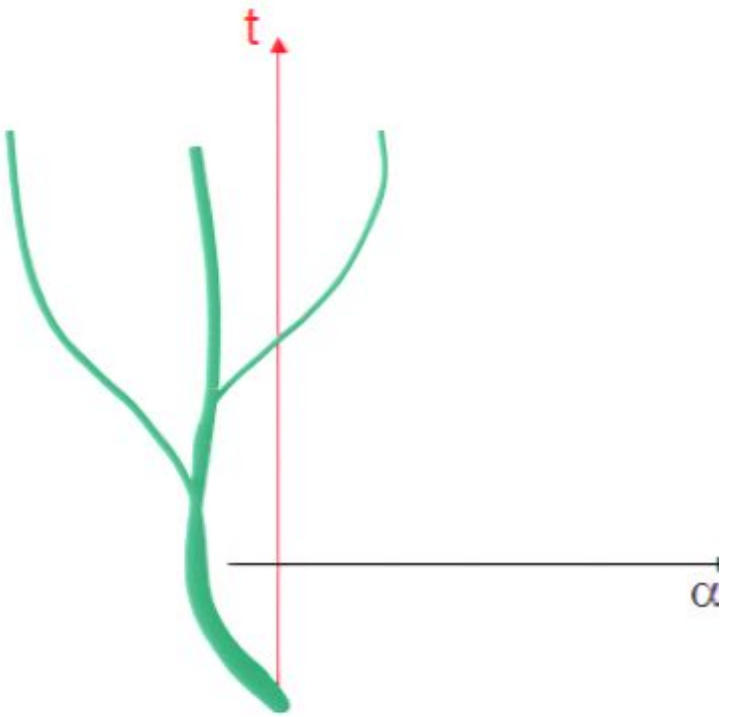

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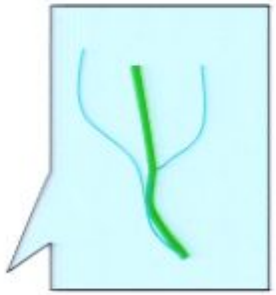

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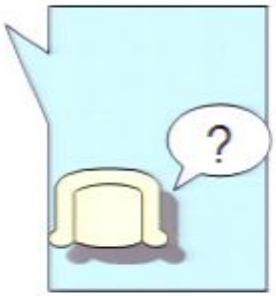

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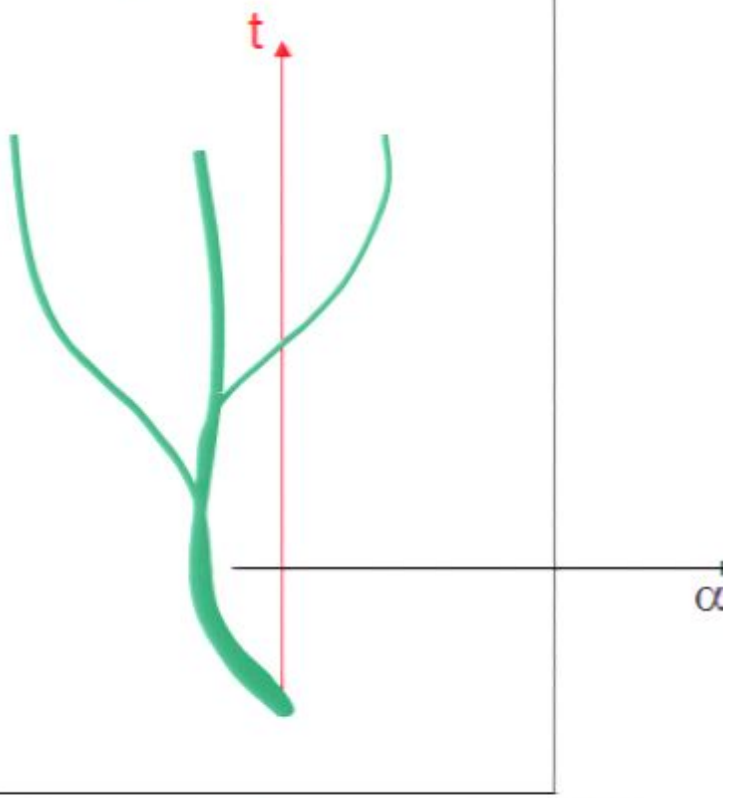
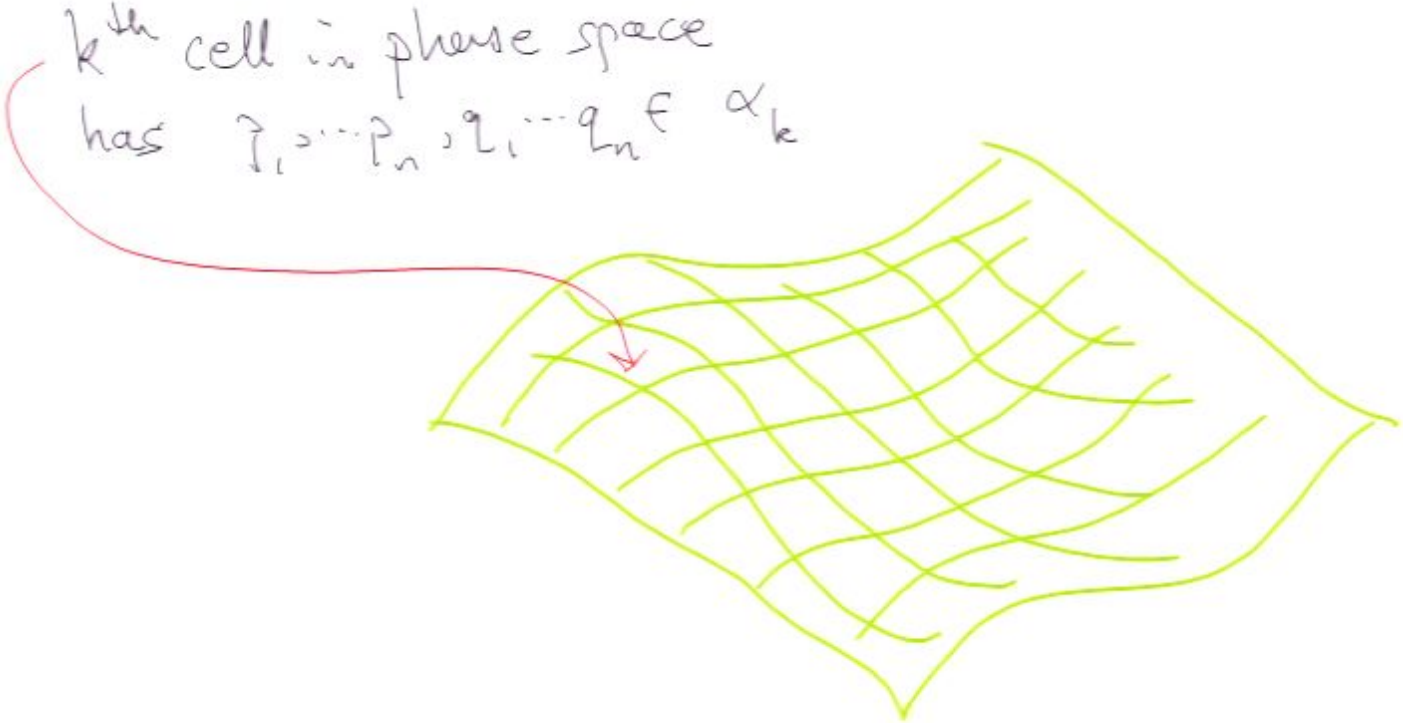


Decoherence theory


k^{th} cell in phase space
has $p_1 \cdots p_n, q_1 \cdots q_n \in \alpha_k$

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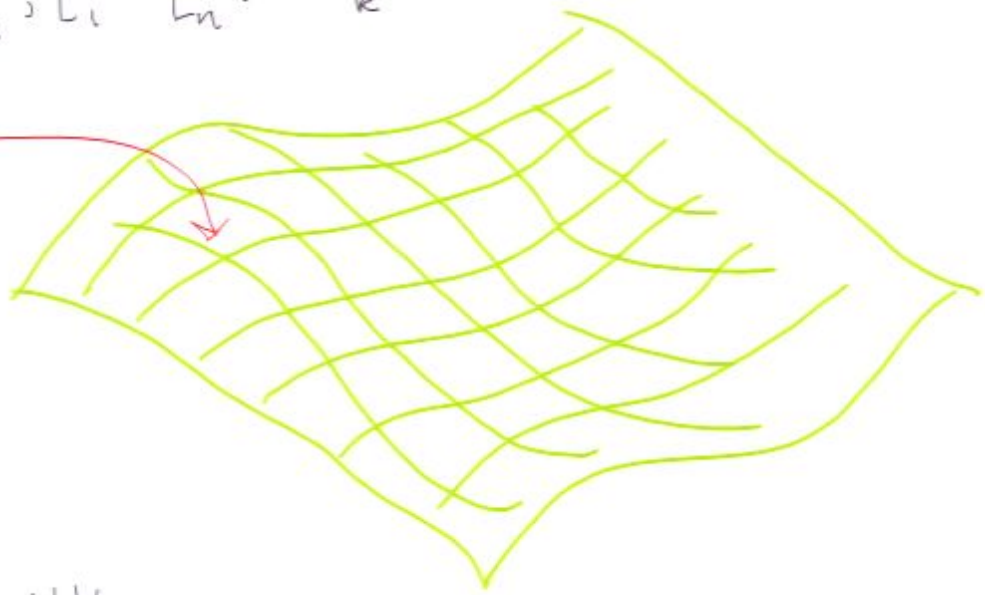


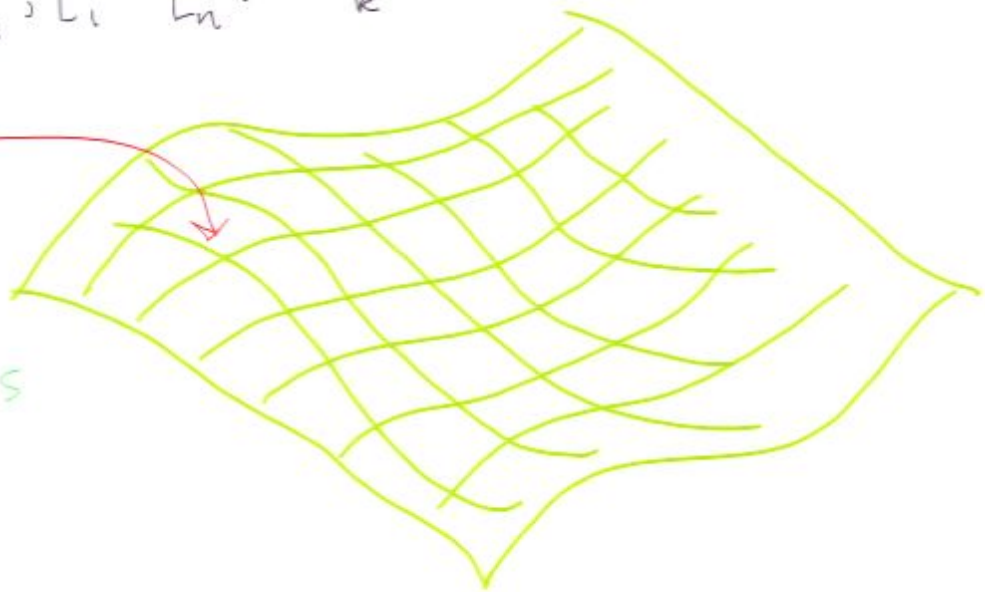
Define Heisenberg picture operators

$$P_{\alpha_k}(t) = e^{-iHt} P_{\alpha_k} e^{iHt}$$

A 'history' is a sequence of such projections

$$C_\alpha = P_{\alpha_k}(t_n) \cdots P_{\alpha_j}(t_1)$$

k^{th} cell in phase space has $p_1, \cdots p_n, q_1, \cdots q_n \in \alpha_k$



'Absolute' probability of a history α in state ψ is

$$W_\psi(\alpha) = \| C_\alpha \psi \|^2$$

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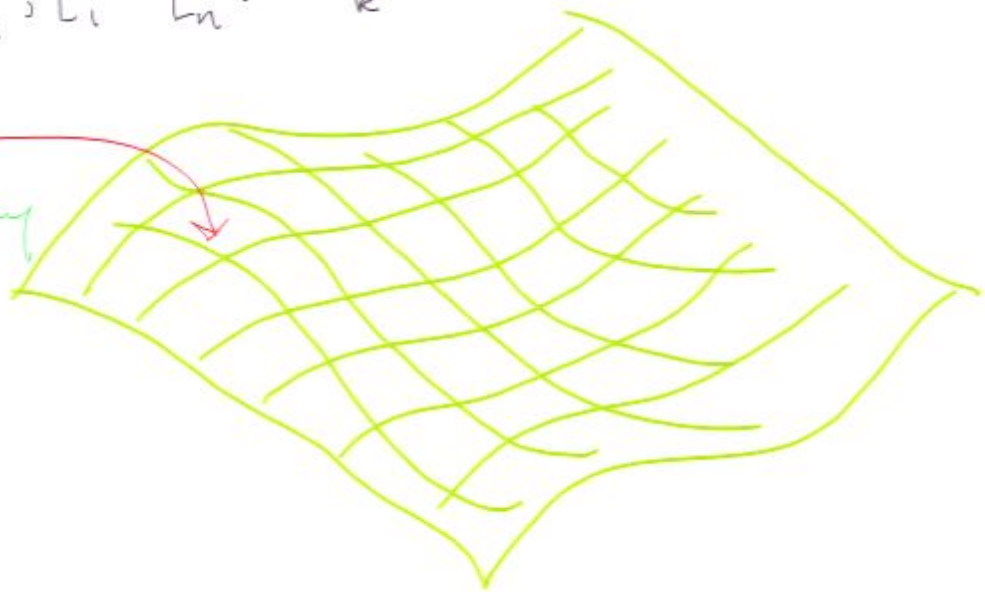


Conditional or relative probability

$$W_\psi(\alpha/\beta) = \frac{\| C_\alpha C_\beta \psi \|^2}{\| C_\beta \psi \|^2}$$

Consistency conditions of the form:

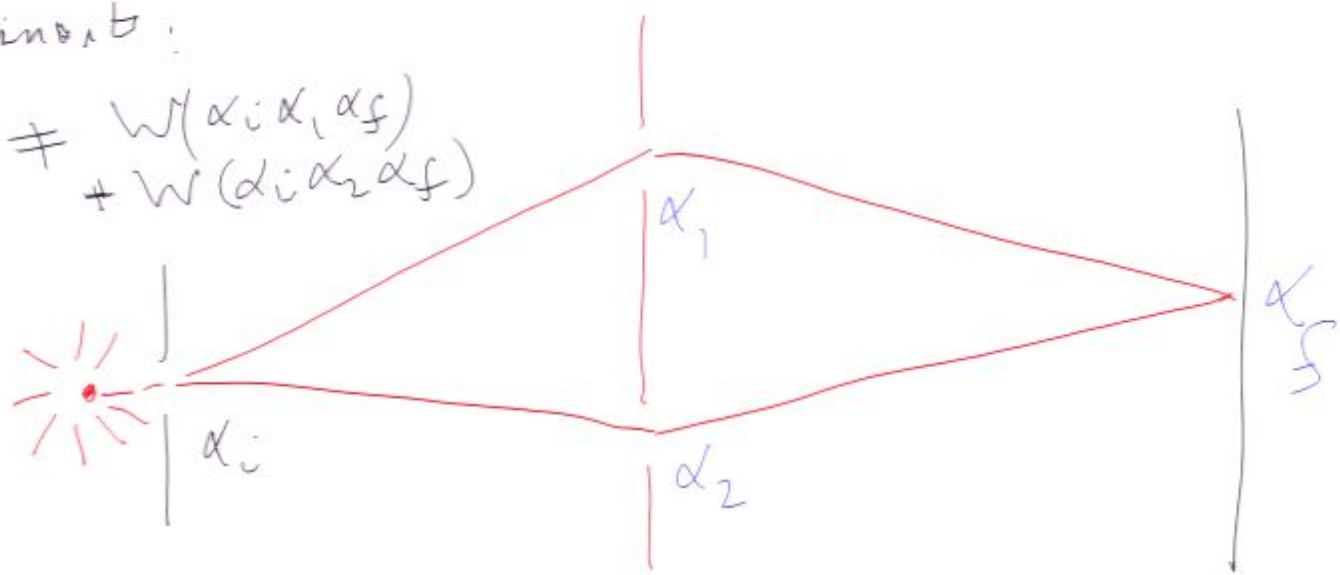
$$W(\alpha_i, \alpha_k) = \sum_{\alpha_j} W(\alpha_i \alpha_j \alpha_k)$$

satisfied if $\{C_\alpha \psi\}$ are orthogonal

$$\langle C_\alpha \psi, C_\beta \psi \rangle = 0 \quad \text{if} \quad \alpha \neq \beta$$

Two slit experiment:

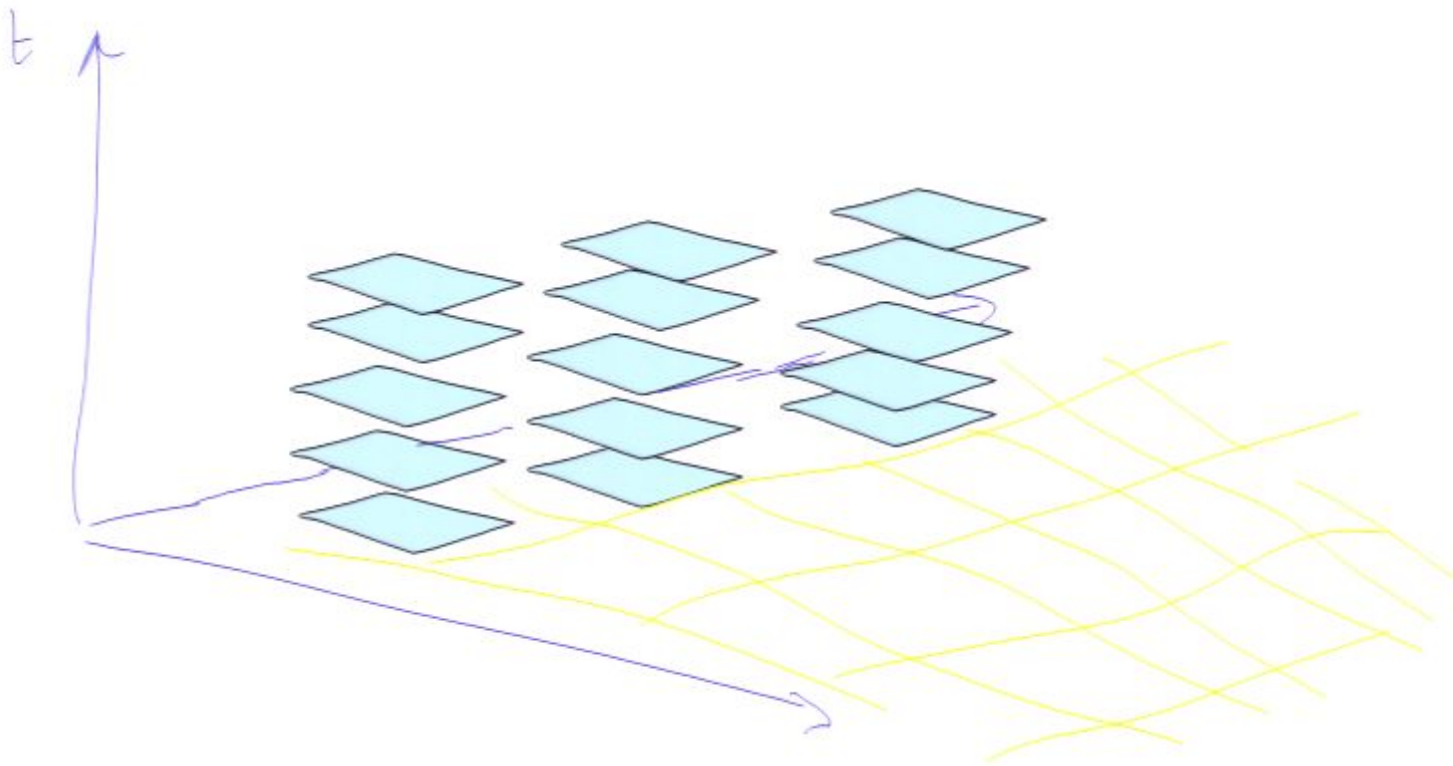
$$W(\alpha_i, \alpha_f) \neq W(\alpha_i \alpha_1 \alpha_f) + W(\alpha_i \alpha_2 \alpha_f)$$



A consistent or decoherent history space

requires a choice of projections at each time t_k

summing to unity satisfying the consistency condition



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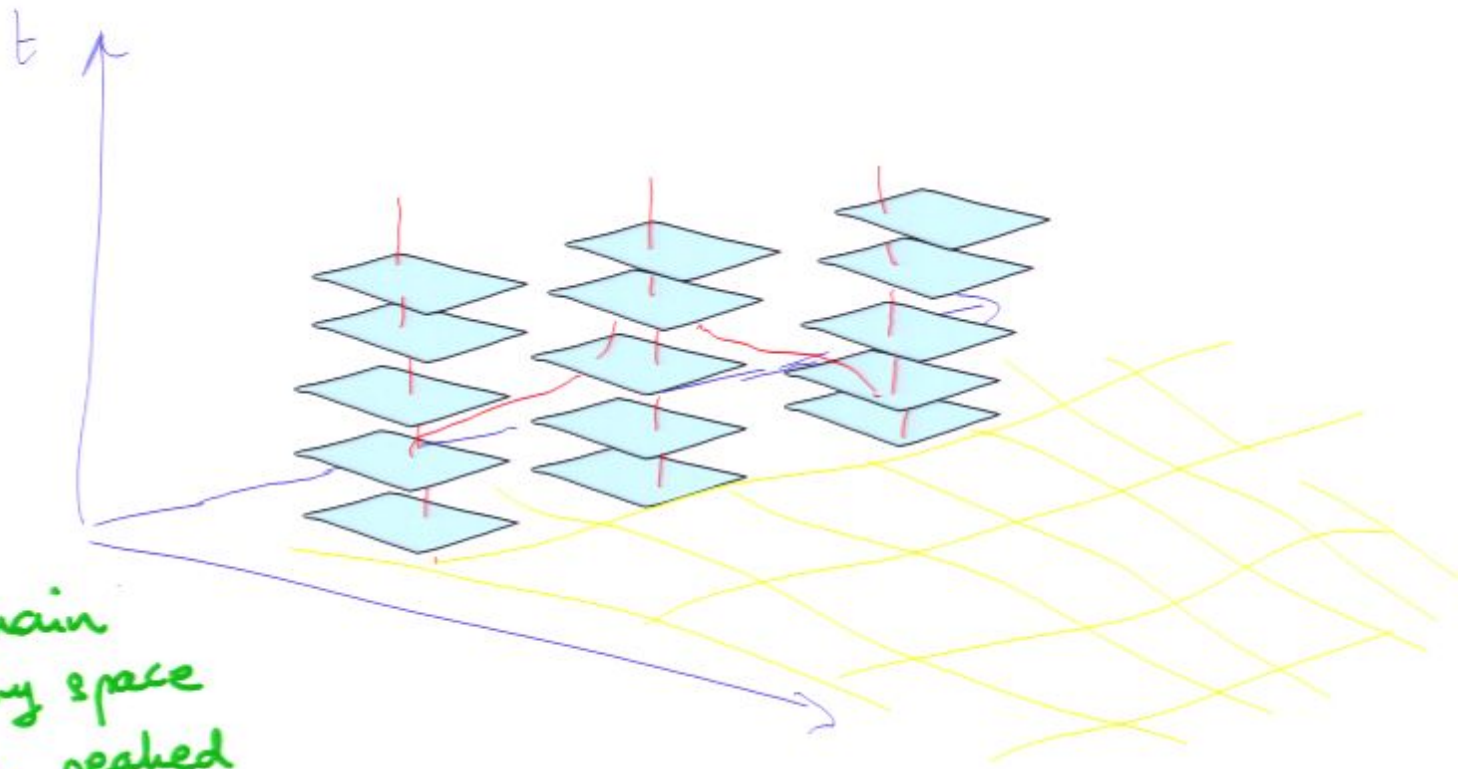

A quasiclassical domain

is a consistent history space

and a state sharply peaked

on histories obeying approximately classical

deterministic equations

A formulation of the expression $\langle C_\alpha \psi, C_\beta \psi \rangle$ when the projections are coarse-grainings in q at time t:

$$\mathcal{D}(q'(t), q(t)) = \delta(q'_f - q_f) \exp\left[\frac{i}{\hbar}\left(S(q) - S(q')\right)\right] \rho(q'_0, q_0)$$

$$\mathcal{D}(\Delta\alpha', \Delta\alpha) = \int_{q' \in \Delta\alpha'} \delta q' \int_{q \in \Delta\alpha} dq$$

$$= \int \delta q' \int dq\, \delta(q'_f - q_f) \exp\left[\frac{i}{\hbar}\left(S_{free}(q') - S_{free}(q) + W(q', q)\right)\right] \rho(q', q)$$

where

$$W(q', q) = -M\gamma \int dt \left(q'\dot{q}' - q\dot{q} - \dot{q}'q - \dot{q}'q\right) + i\frac{2M\gamma kT}{\hbar} \int dt \left[q'(t) - q(t)\right]^2$$

Decoherence time $t \sim \frac{1}{\gamma}\left[\frac{\hbar}{\sqrt{2MkT}}\frac{1}{d}\right]^2$

thermal relaxation time

$t\gamma \sim 1$ for small molecules

$T \sim 300K$

$d \sim$ small molecules

$$= \int \delta q' \int \delta q\, \delta(q'_f - q_f) \exp\left[\frac{i}{\hbar}\left(S_{free}(q') - S_{free}(q) + W(q',q)\right)\right] \rho(q',q)$$

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decoherence

examples:

Brownian motion (density matrix approach)
Joos + Zeh 1985
(quantum state diffusion)
Zurek 1994, 2001,
Halliwell + Zapata 1997.

Diffusion in fluids + gases (hydrodynamic variables)
Halliwell 1998.

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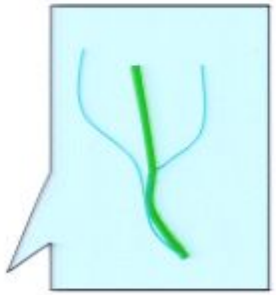

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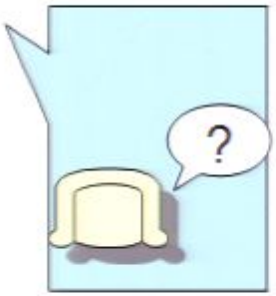

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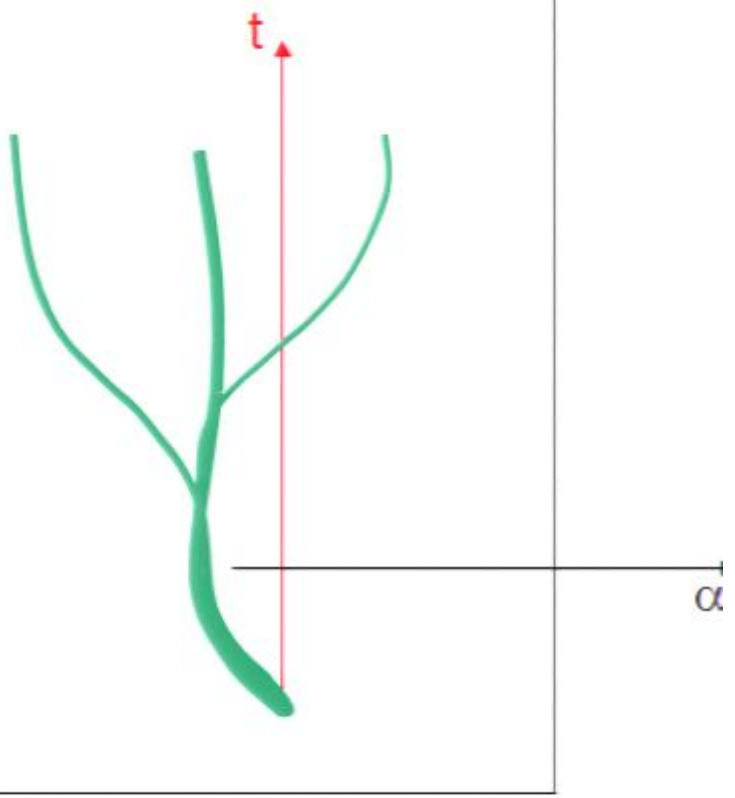

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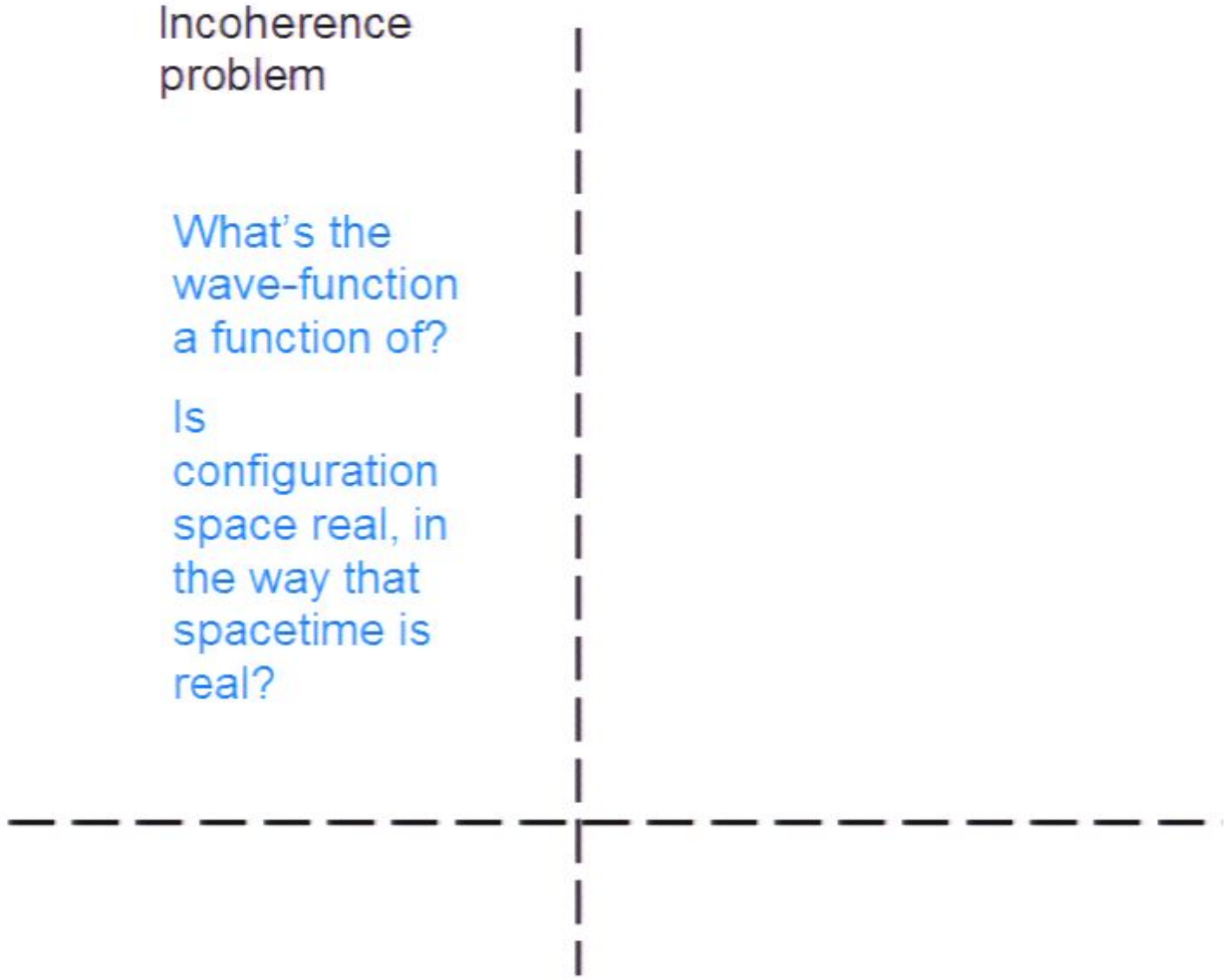
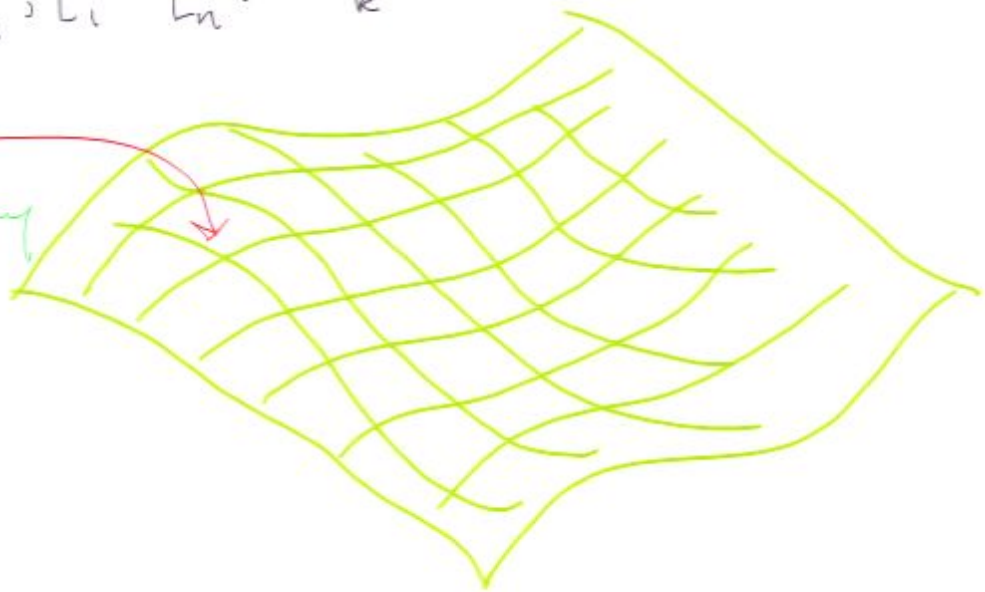


k^{th} cell in phase space has $p_1, \cdots p_n, q_1, \cdots q_n \in \alpha_k$

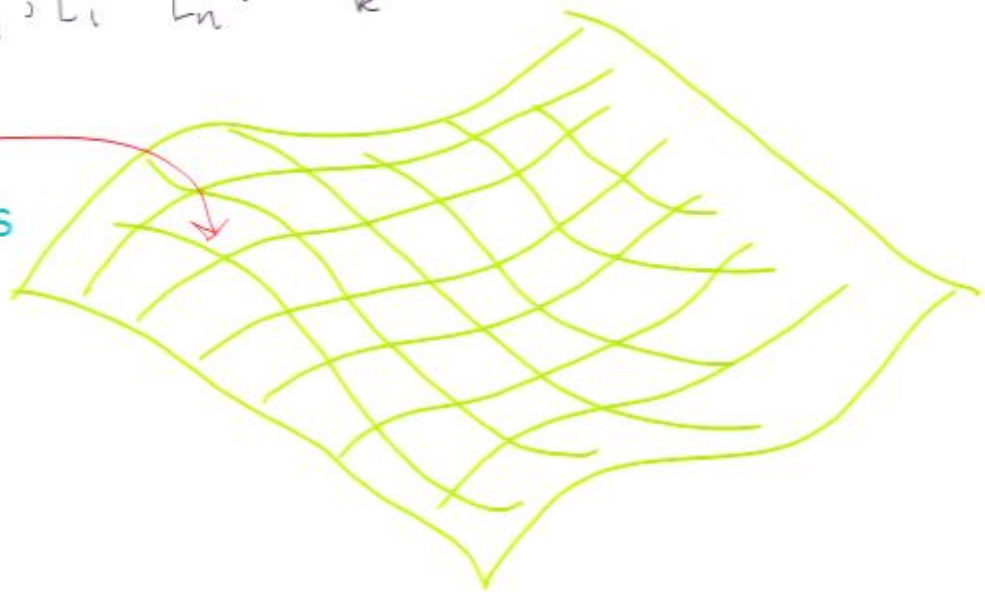


Conditional or relative probability

$$W_\psi(\alpha/\beta) = \frac{\| C_\alpha C_\beta \psi \|^2}{\| C_\beta \psi \|^2}$$

k^{th} cell in space of canonical coordinates

has $p_1, \dots p_n, q_1, \dots q_n \in \alpha_k$



Conditional or relative correlations

$$W_\psi(\alpha/\beta) = \frac{\| C_\alpha C_\beta \psi \|^2}{\| C_\beta \psi \|^2}$$

$$\psi \otimes \eta_0 \otimes (c_+ \phi_+ + c_- \phi_-)$$

$$\longrightarrow \psi \otimes (c_+ \eta_+ \otimes \phi_+ + c_- \eta_- \otimes \phi_-)$$

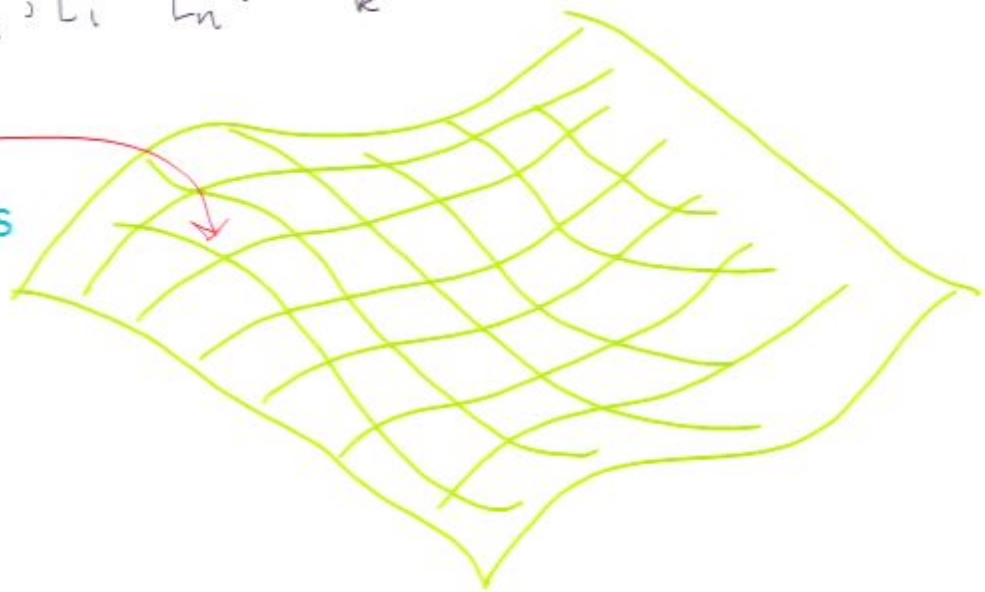
$$\longrightarrow c_+ \psi_+ \otimes \eta_+ \otimes \phi_+ + c_- \psi_- \otimes \eta_- \otimes \phi_-$$

'Relative state' of η_+ is ϕ_+

" " " η_- is ϕ_-

k^{th} cell in space of canonical coordinates

has $p_1 \cdots p_n, q_1 \cdots q_n \in \alpha_k$



Conditional or relative correlations

$$W_\psi(\alpha/\beta) = \frac{\| C_\alpha C_\beta \psi \|^2}{\| C_\beta \psi \|^2}$$

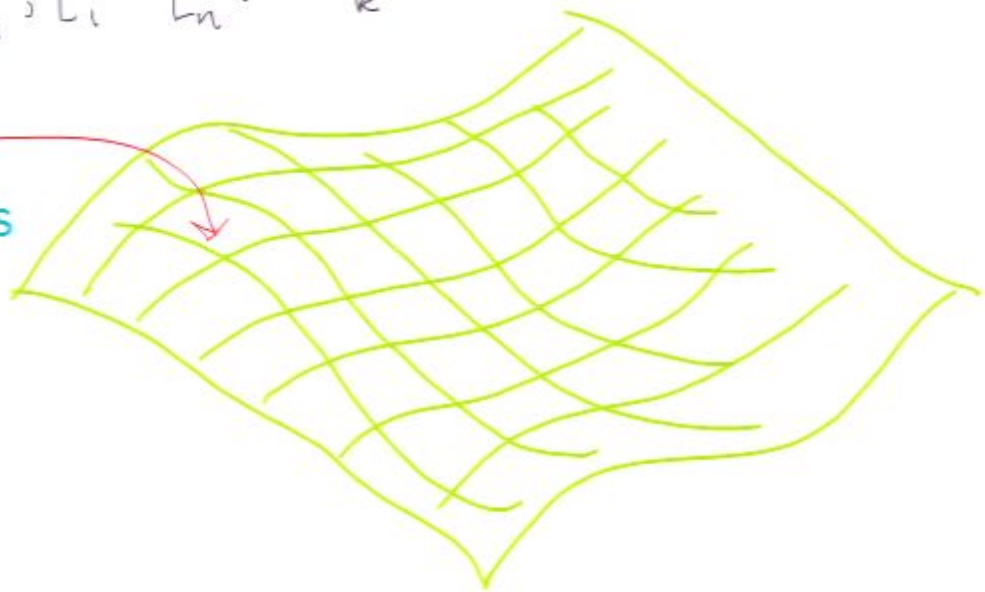
Define relation 'Def_ρ' as:

$Def_\rho(\alpha_k/\alpha_j)$ iff $W_\psi(\alpha_k/\alpha_j) = 1$

read as:

"Configuration α_k is value definite relative to α_j in state ρ"

k^{th} cell in space of canonical coordinates has $p_1 \cdots p_n, q_1 \cdots q_n \in \alpha_k$

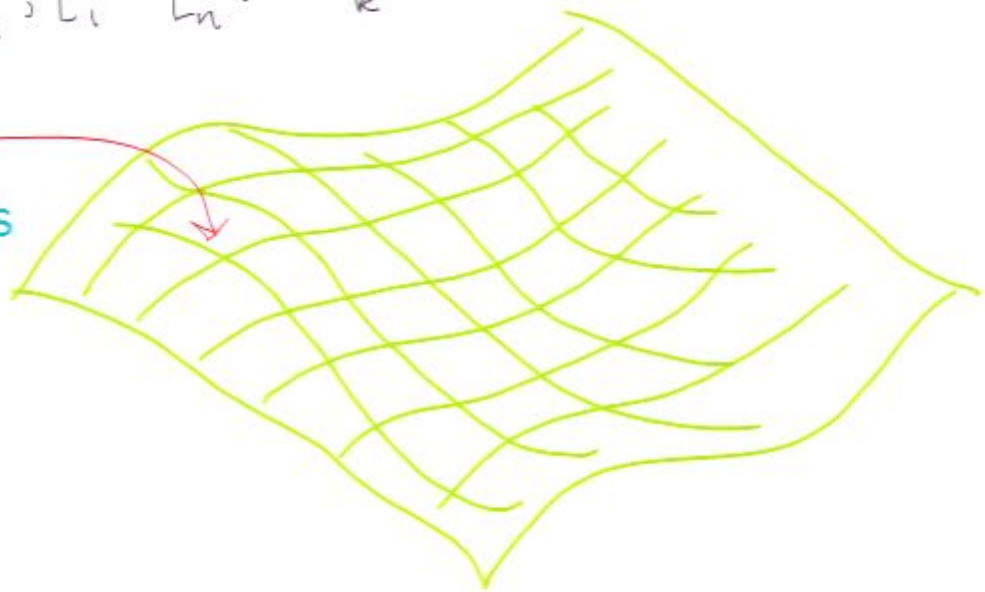


Conditional or relative correlations

$$W_\psi(\alpha/\beta) = \frac{\| C_\alpha C_\beta \psi \|^2}{\| C_\beta \psi \|^2}$$

Def_ψ is transitive for spacelike projectors and for consistent timelke projectors

k^{th} cell in space of canonical coordinates has $p_1, \dots p_n, q_1, \dots q_n \in \alpha_k$

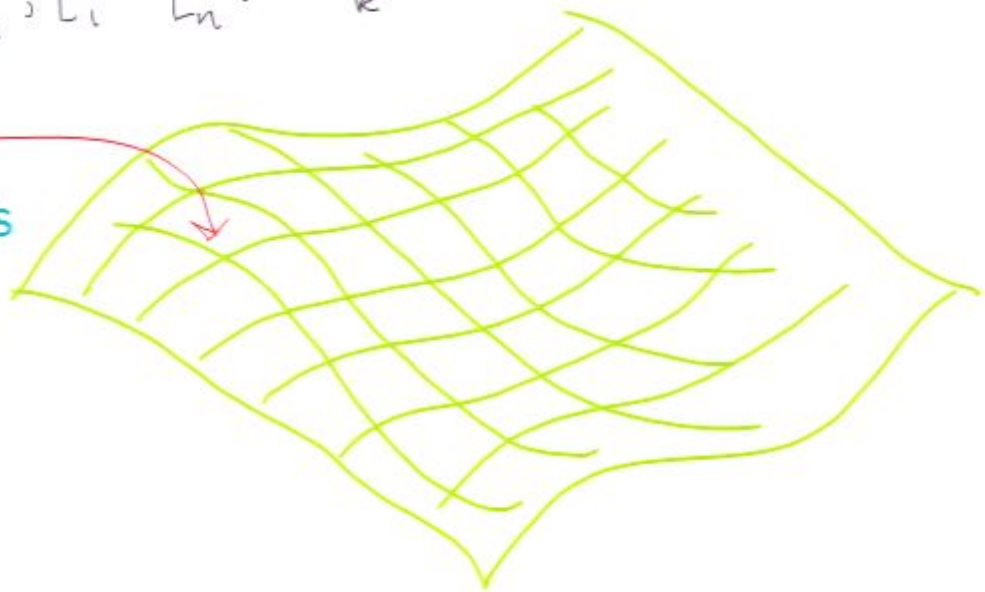


Conditional or relative correlations

$$W_\psi(\alpha/\beta) = \frac{\| C_\alpha C_\beta \psi \|^2}{\| C_\beta \psi \|^2}$$

In a quantum mechanical particle theory:

k^{th} cell in space of canonical coordinates has $p_1 \cdots p_n, q_1 \cdots q_n \in \alpha_k$

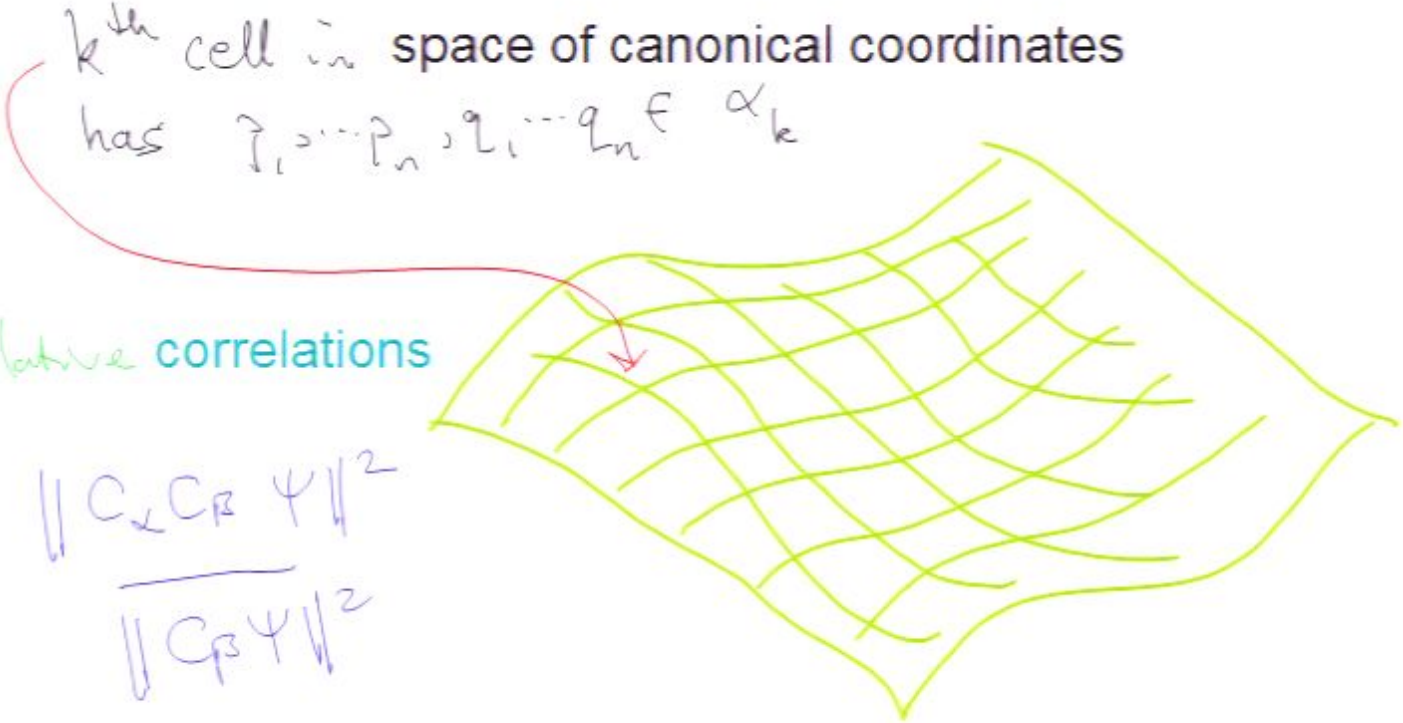


Conditional or relative correlations

$$W_\psi(\alpha/\beta) = \frac{\| C_\alpha C_\beta \psi \|^2}{\| C_\beta \psi \|^2}$$

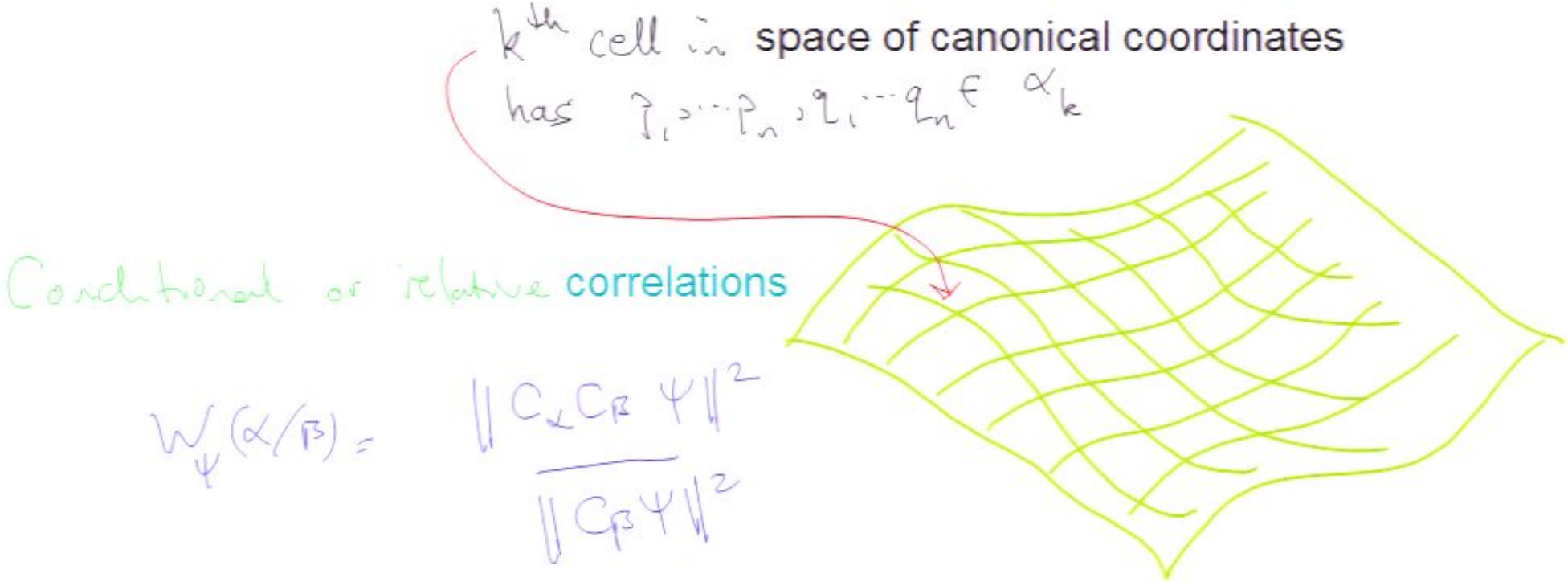
In a quantum mechanical particle theory:

- All correlations among patterns of particles (relative positions and momenta) exist



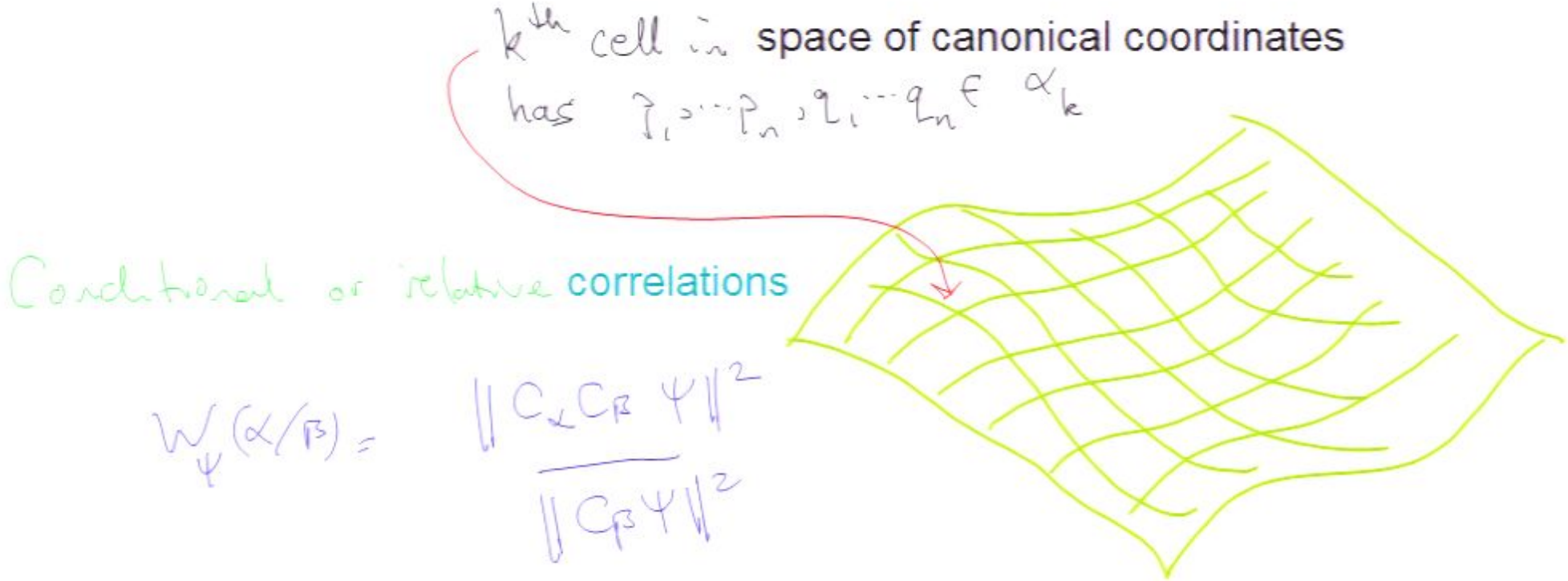
In a quantum mechanical particle theory:

- More generally: all correlations among patterns of polarizations on n-particle phase space exist



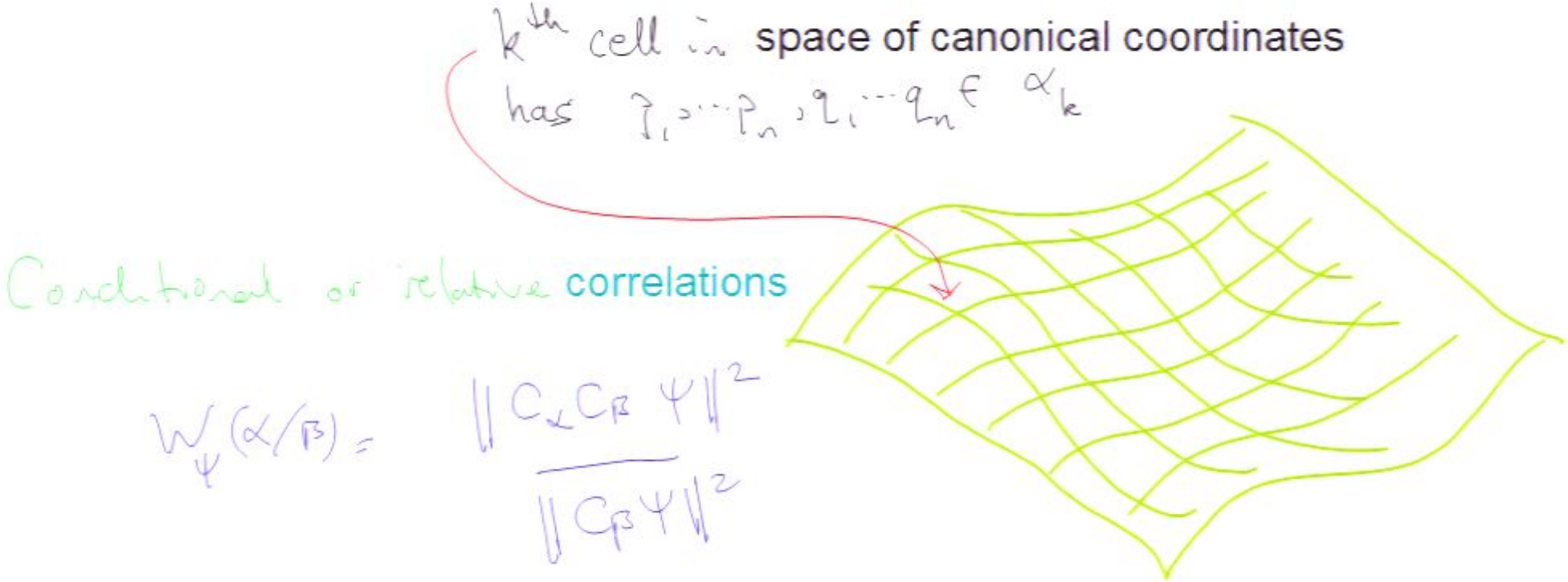
In a quantum mechanical particle theory:

- More rigorously: all correlations among patterns of polarizations on n-particle phase space exist
- as given by invariant relations among projections



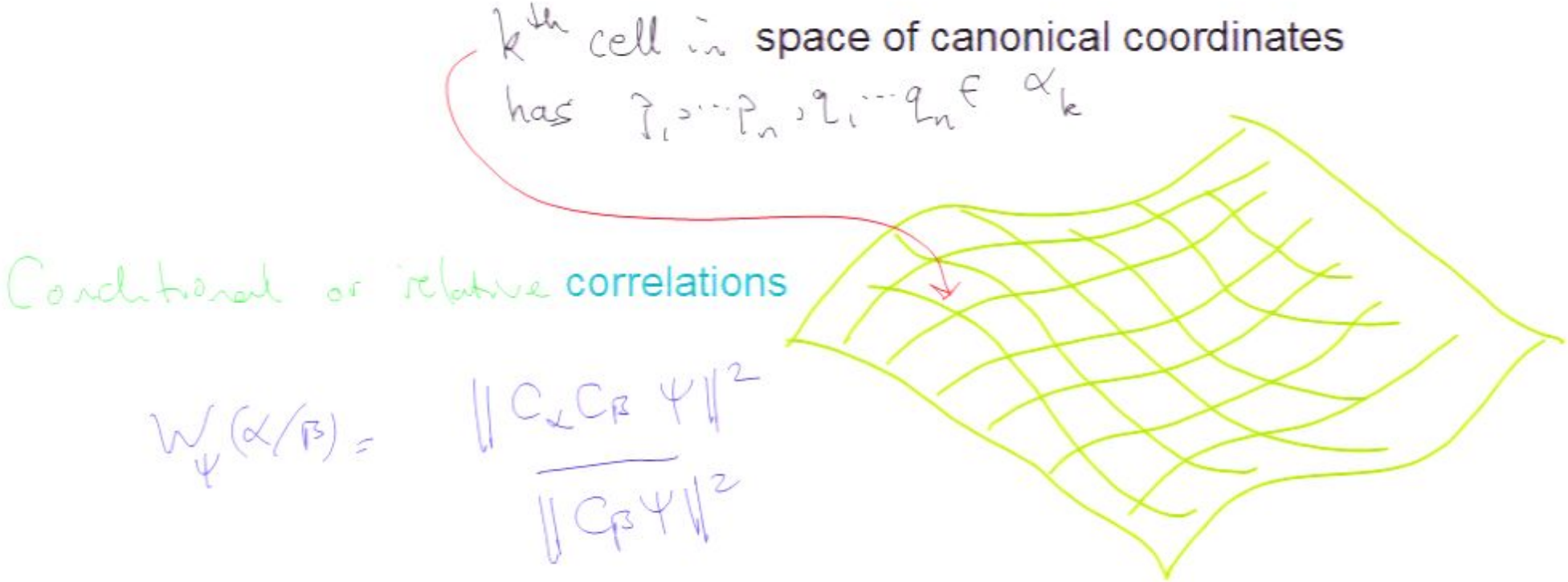
In a quantum mechanical particle theory:

- More rigorously: all correlations among patterns of polarizations on n-particle phase space exist
- as given by invariant relations among projections
- but only some of these correlations among patterns are stable under perturbations (typically coarse-grainings), yielding dynamically decoupled (branching) histories.



In a quantum mechanical field theory:

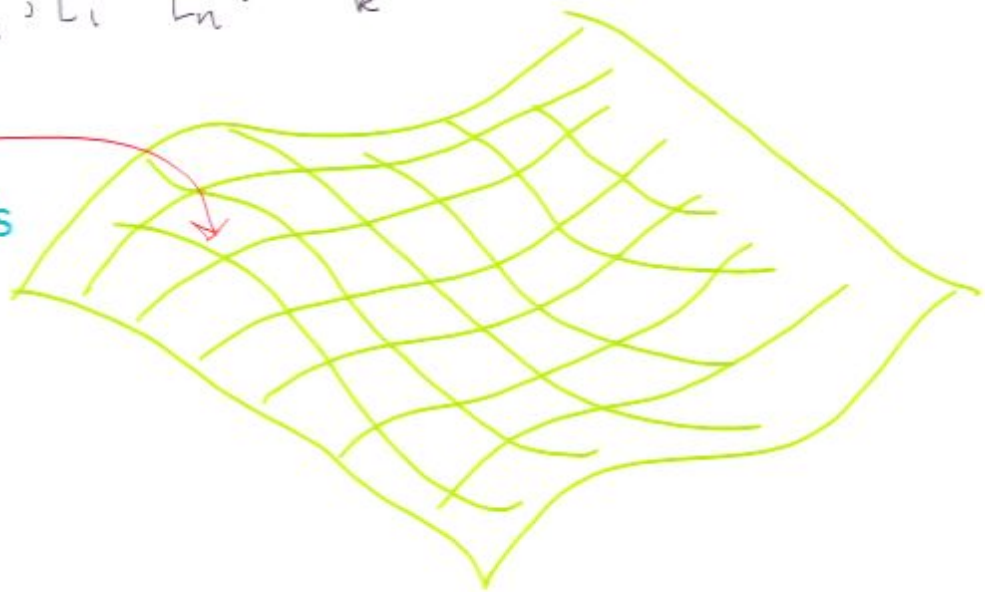
- More rigorously: all correlations among field configurations (polarizations of phase space) exist
- as given by invariant relations among projections
- but only some of these correlations of field configurations are stable under perturbations (typically coarse-grainings), yielding dynamically decoupled (branching) histories.



In classical general relativity:

- All correlations among values of fields on the manifold exist
- as given by diffeomorphic-invariant relations among them
- but only some of these correlations of field configurations are stable under perturbations (typically coarse-grainings), yielding dynamically decoupled (but non-branching) histories

k^{th} cell in space of canonical coordinates has $p_1 \cdots p_n, q_1 \cdots q_n \in \alpha_k$



Conditional or relative correlations

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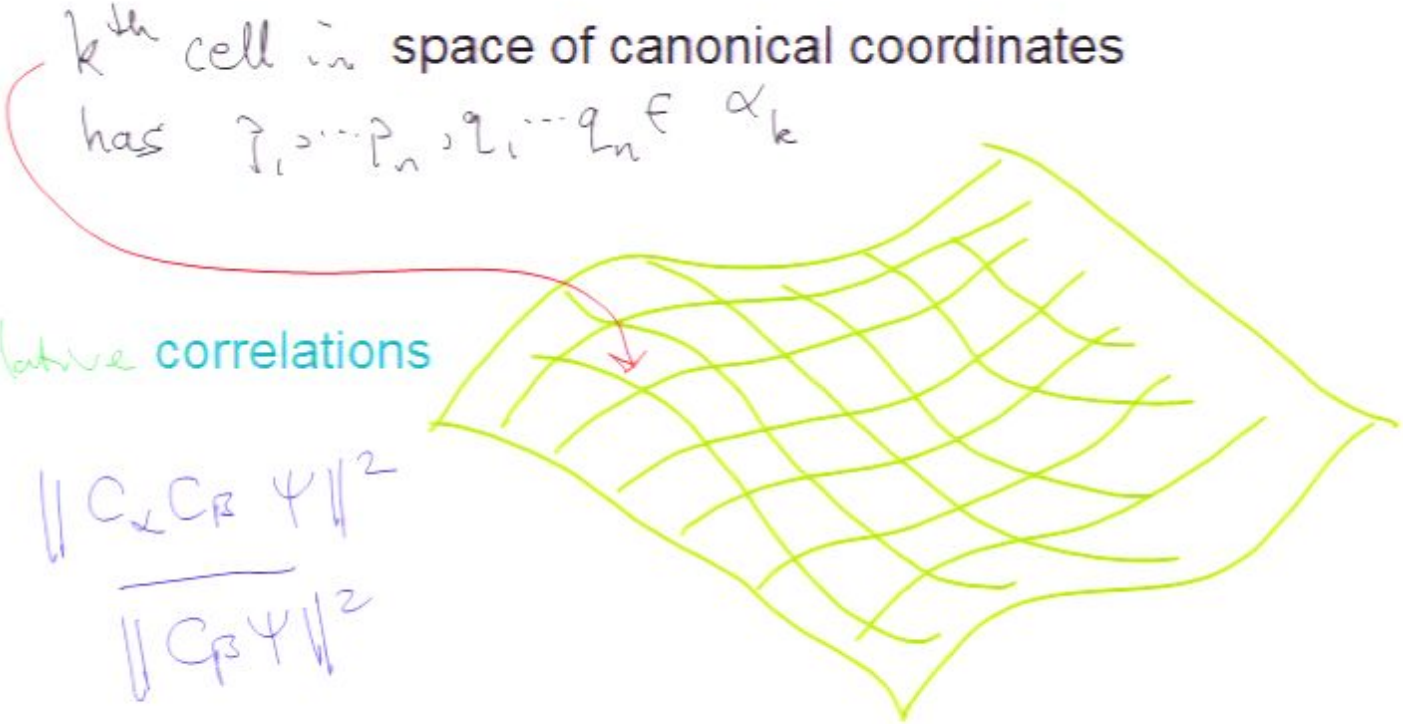
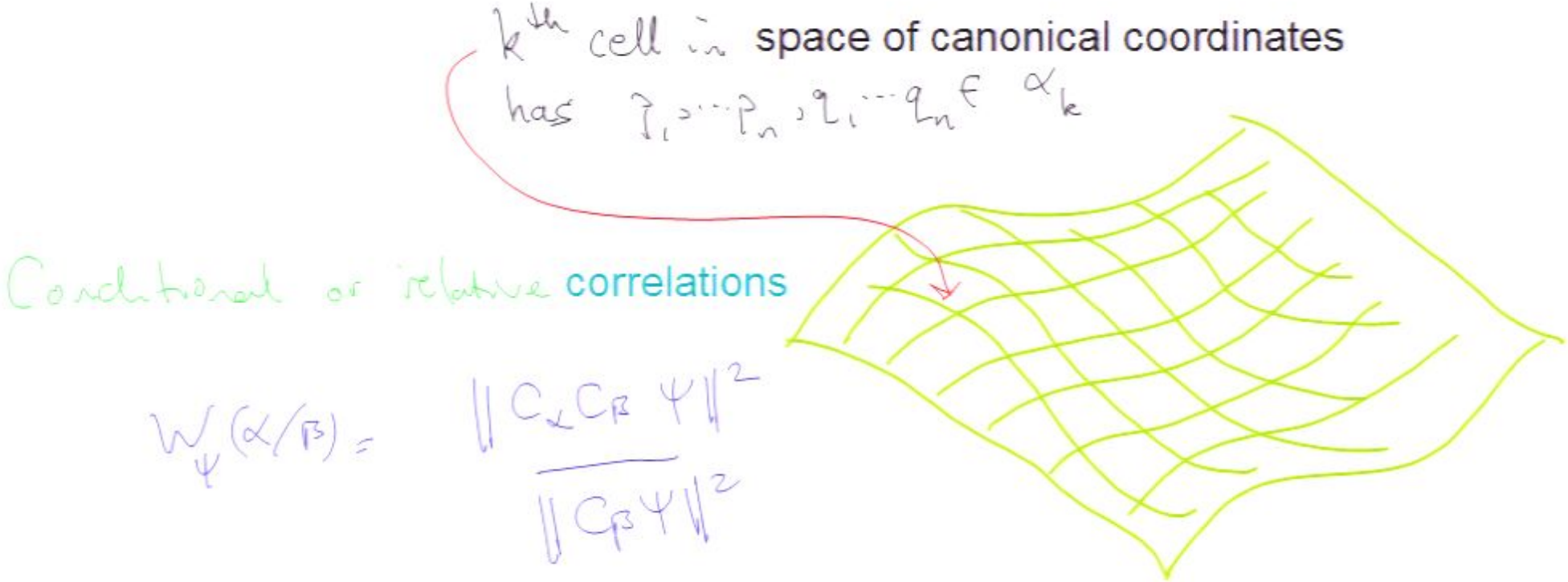
In classical general relativity:

- …like galaxies, stars, planets



In classical general relativity:

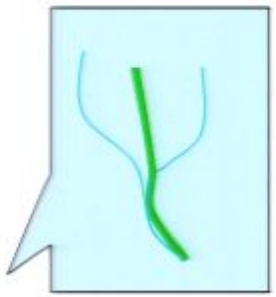
•…patterns of values of fields can be referred to any foliation, but some foliations are more perspicuous than others (simpler, better 'adapted', etc.)



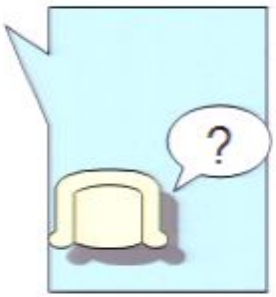
In classical general relativity:

- …patterns of values of fields can be referred to any foliation, but some foliations are more perspicuous than others (simpler, better 'adapted', etc.)
- but only if ALL (correlations among field-values on) leaves of a foliation are real.

Conclusions:

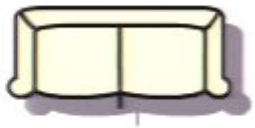


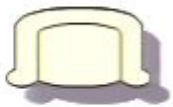
- Ontology
- Probability



Incoherence problem

quantitative problem





Uncertainty intelligible- 'chance'

Given the ontology

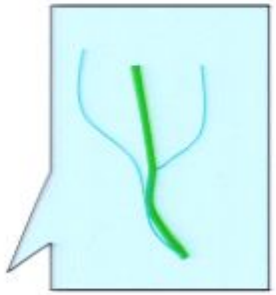
practical problem

Uncertainty unintelligible- 'caring measure'

Not given the ontology

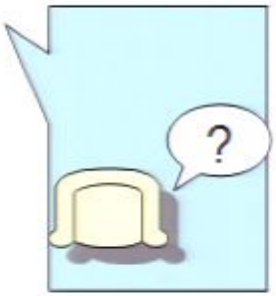
epistemic problem

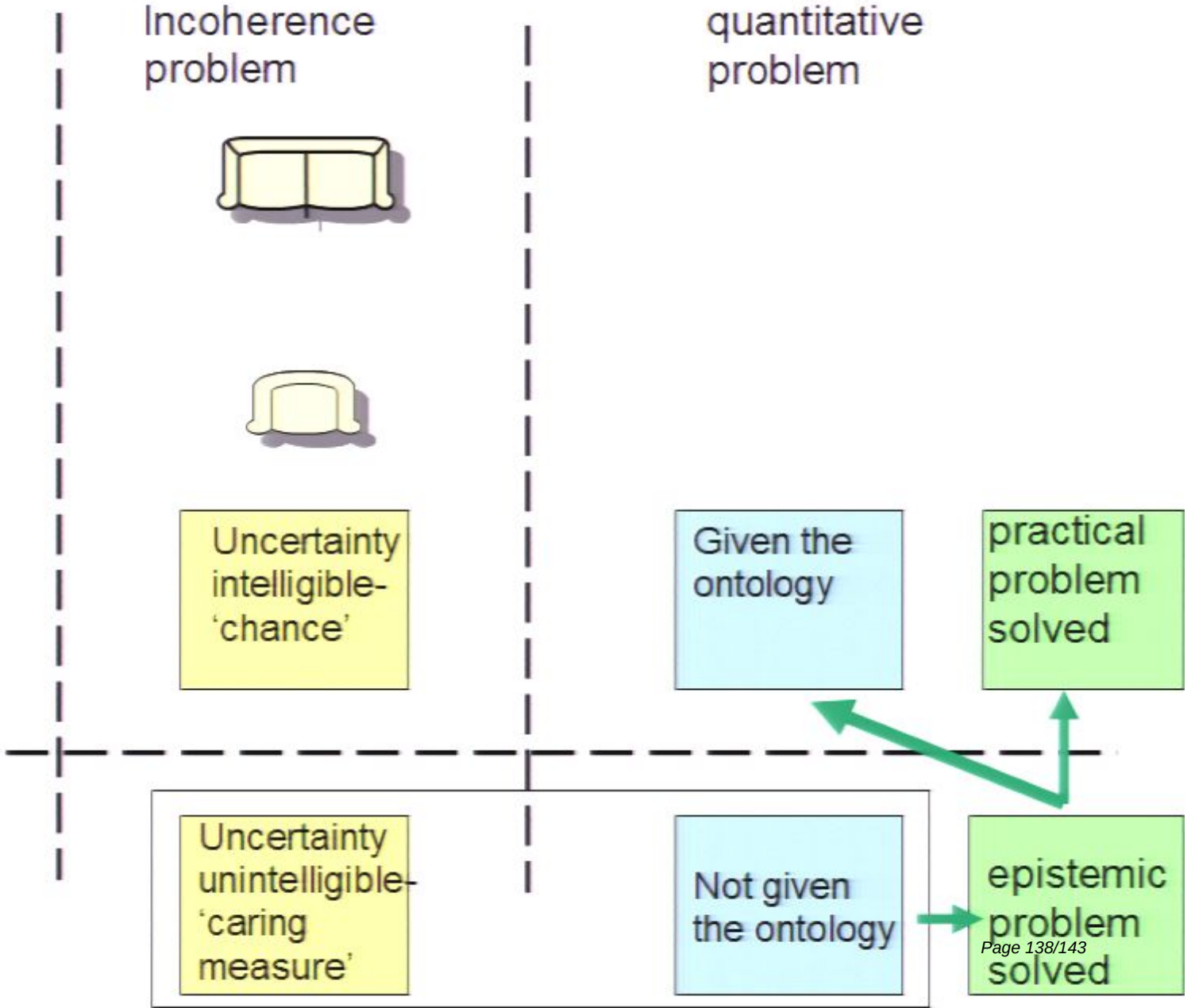
Conclusions:



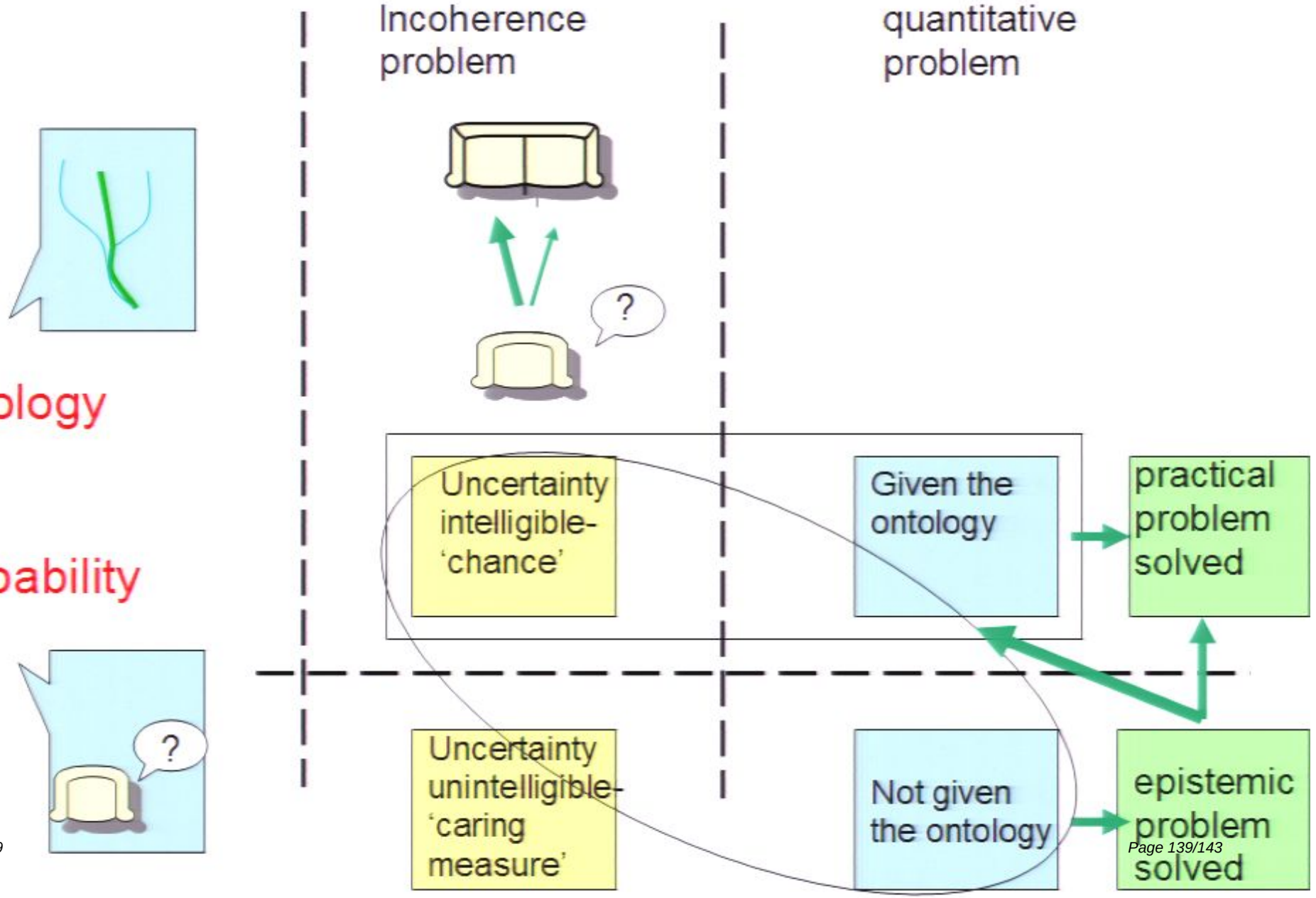
•Ontology

•Probability





Conclusions:



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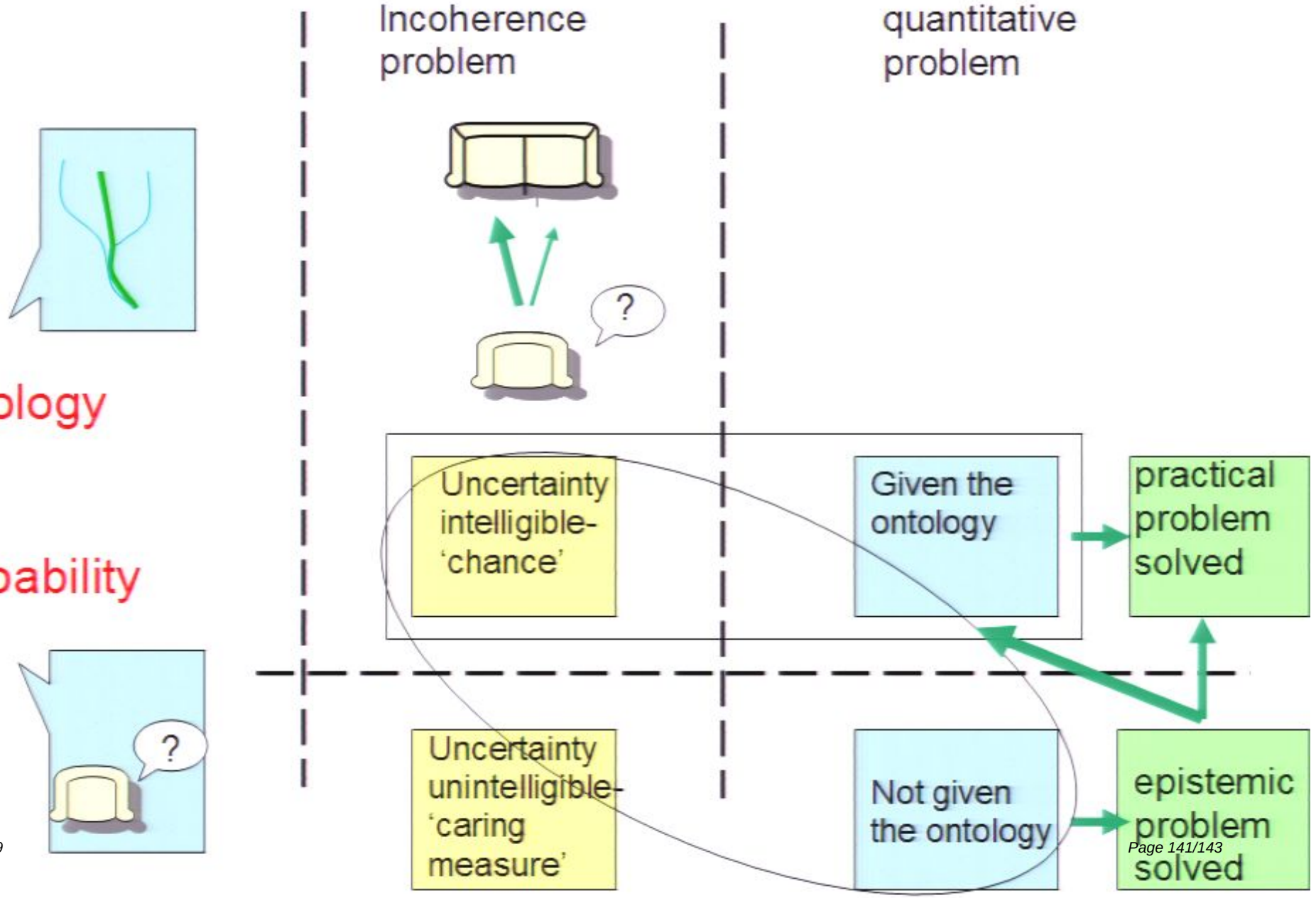
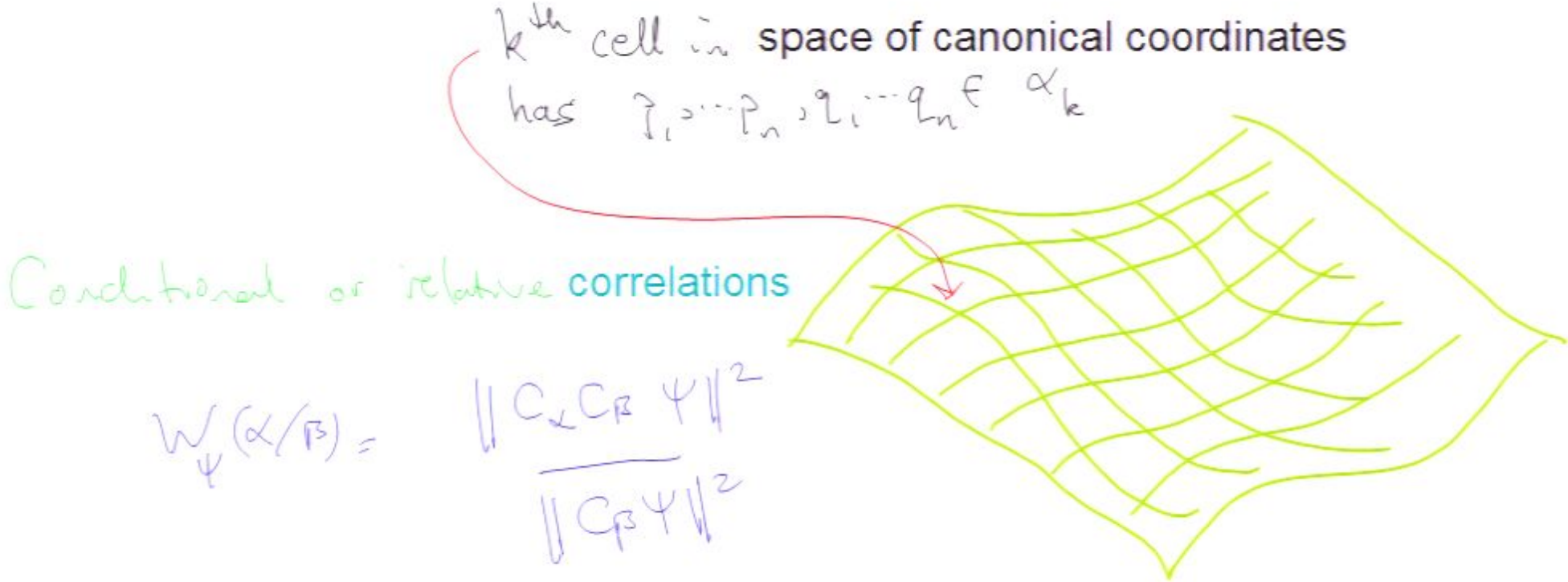
Conclusions:





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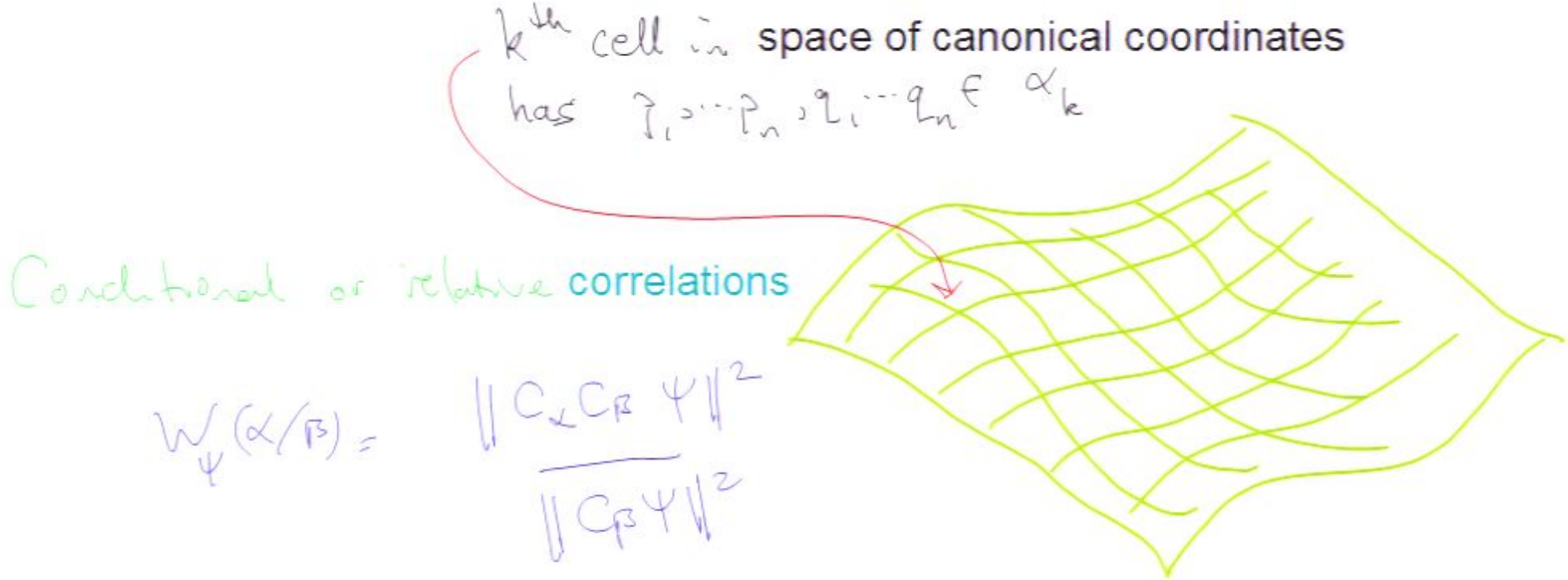

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