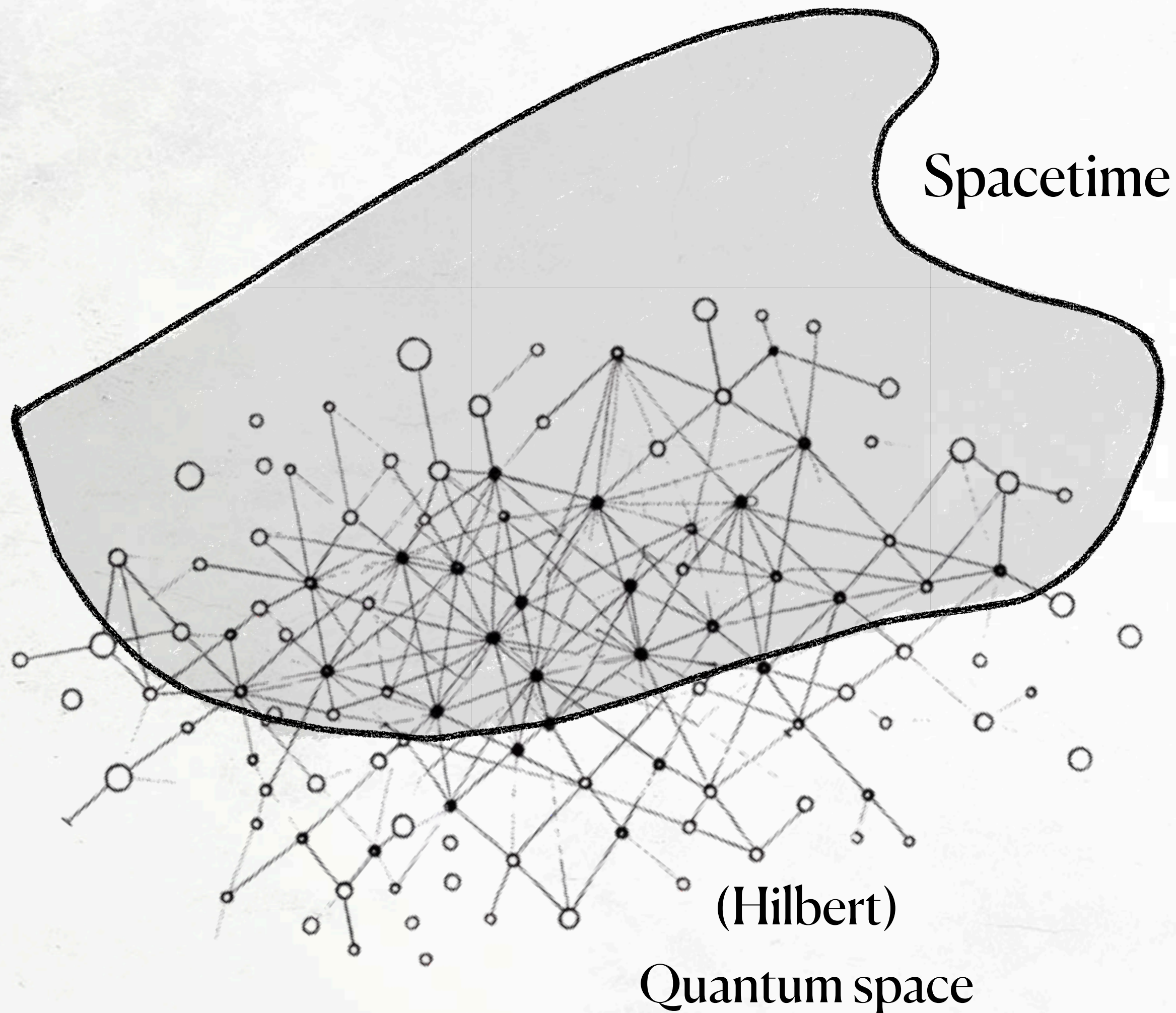


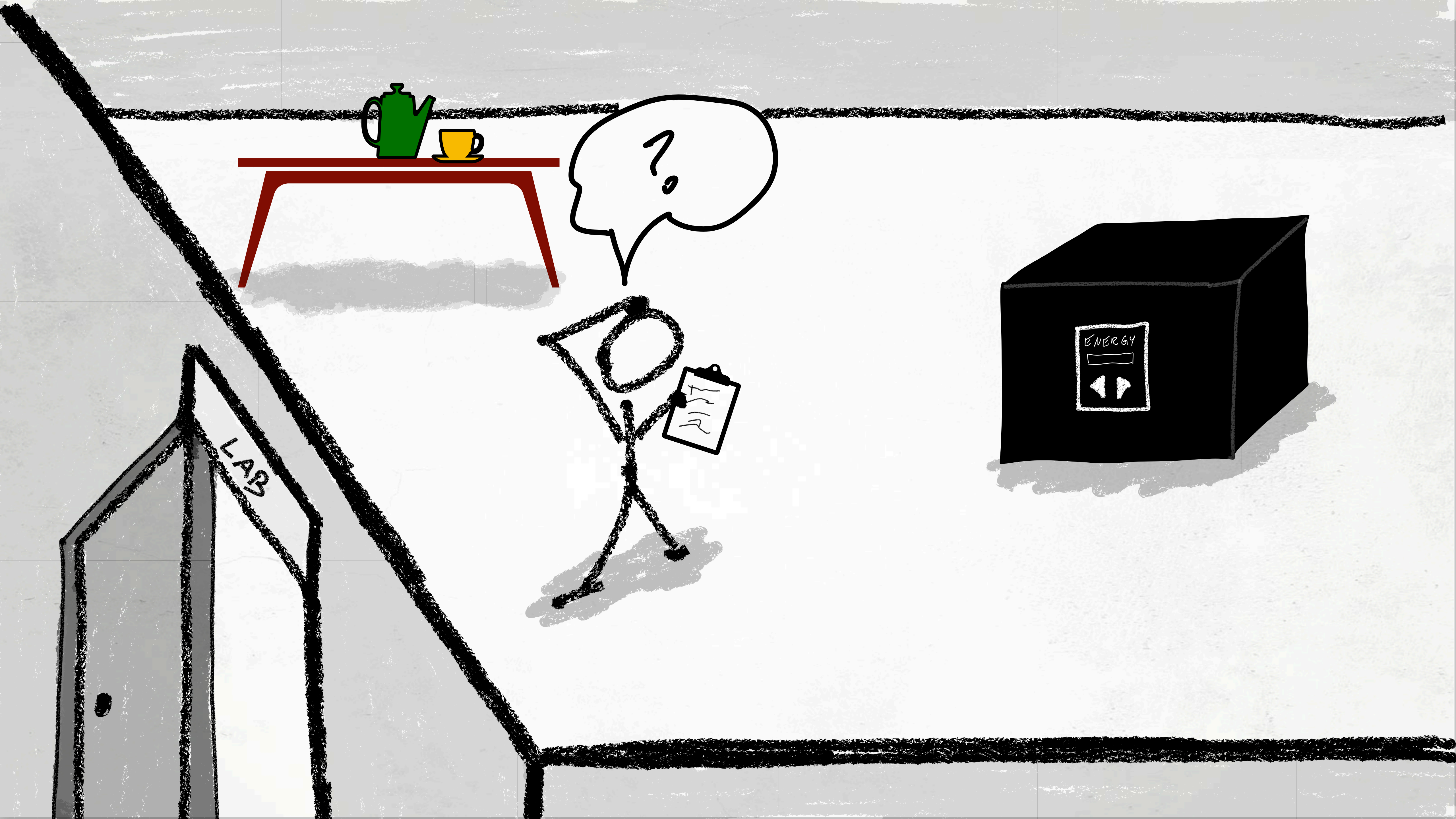
Philosophy of Physics: Final Lecture!

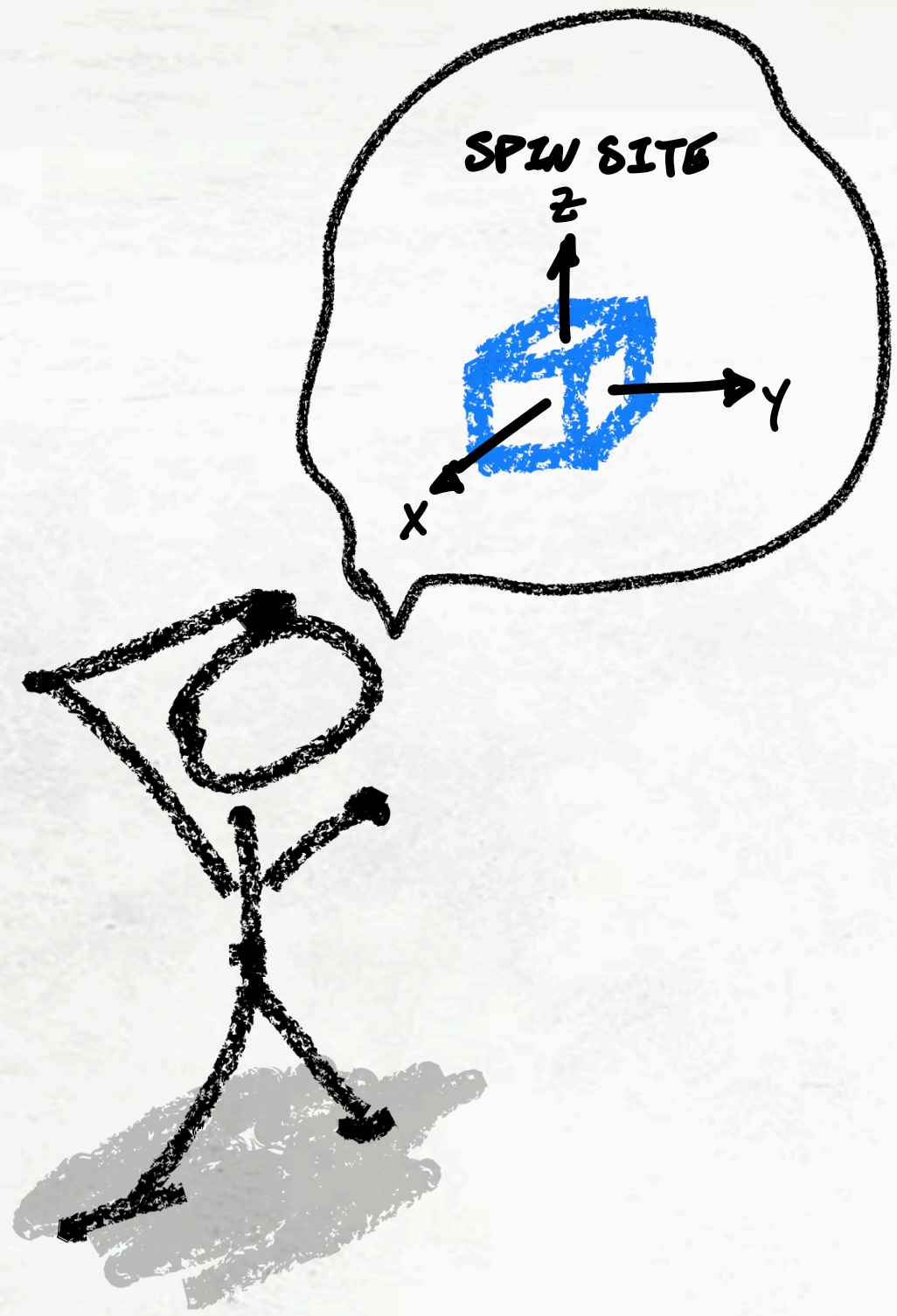
A Tale of Emergence



Chapter 1:

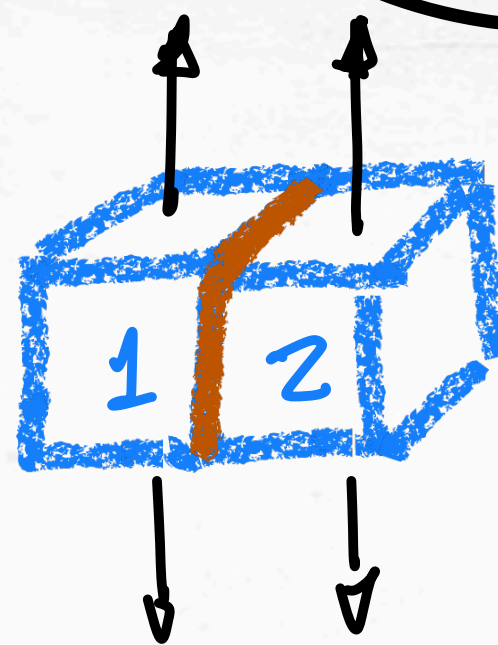
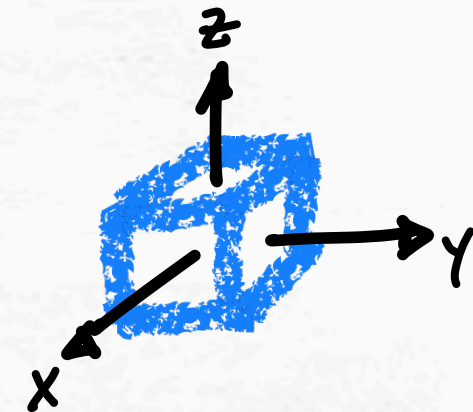
The mysterious box



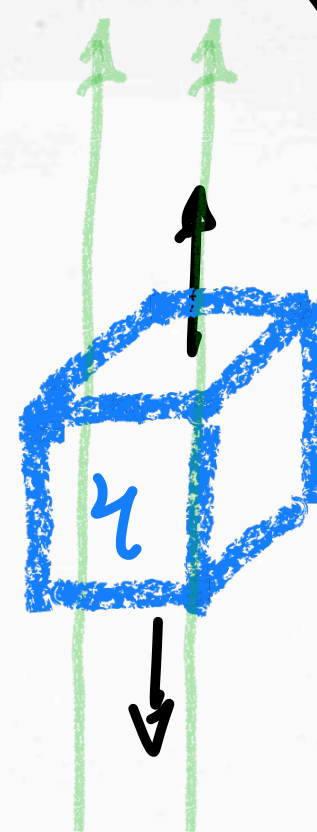




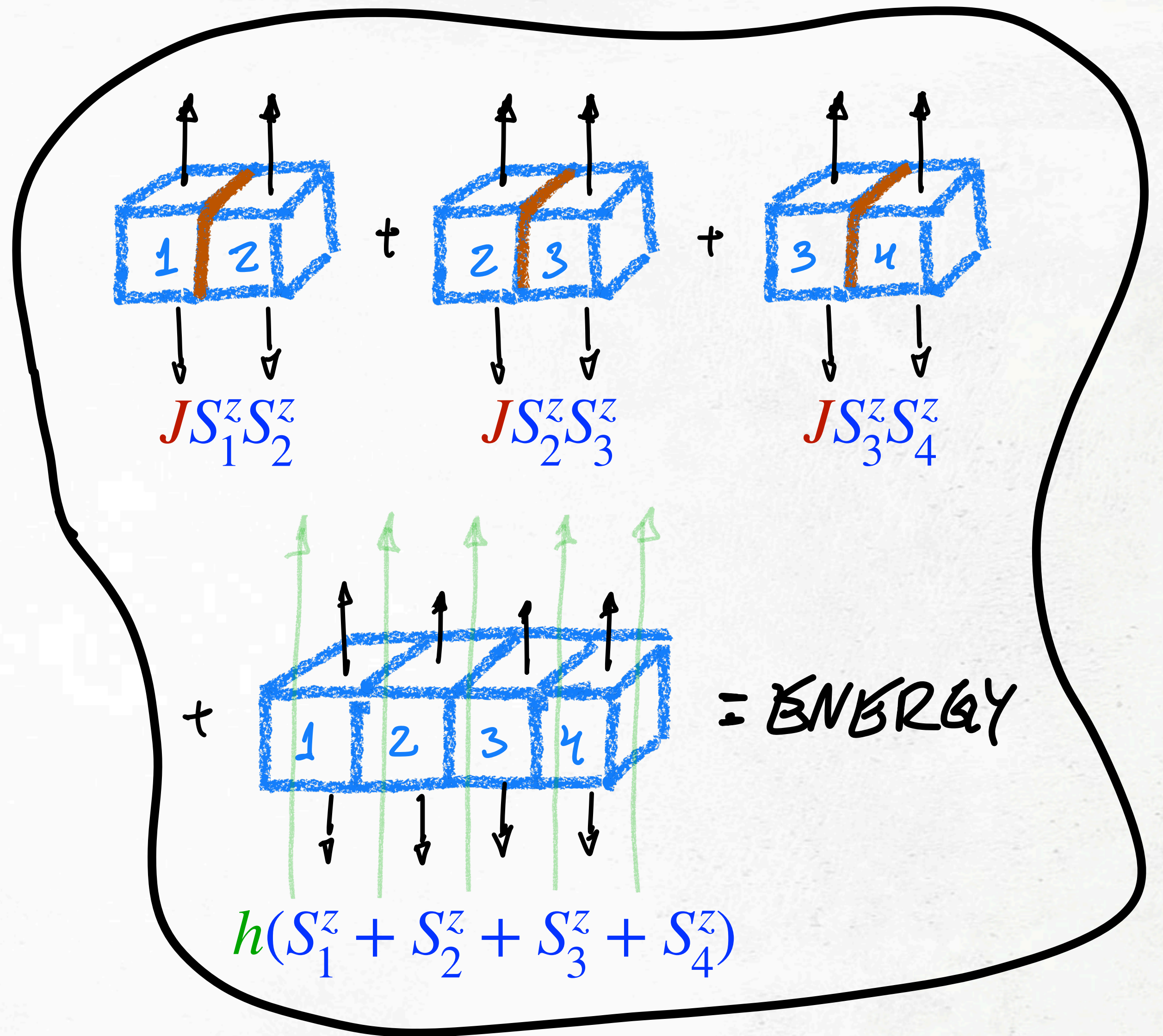
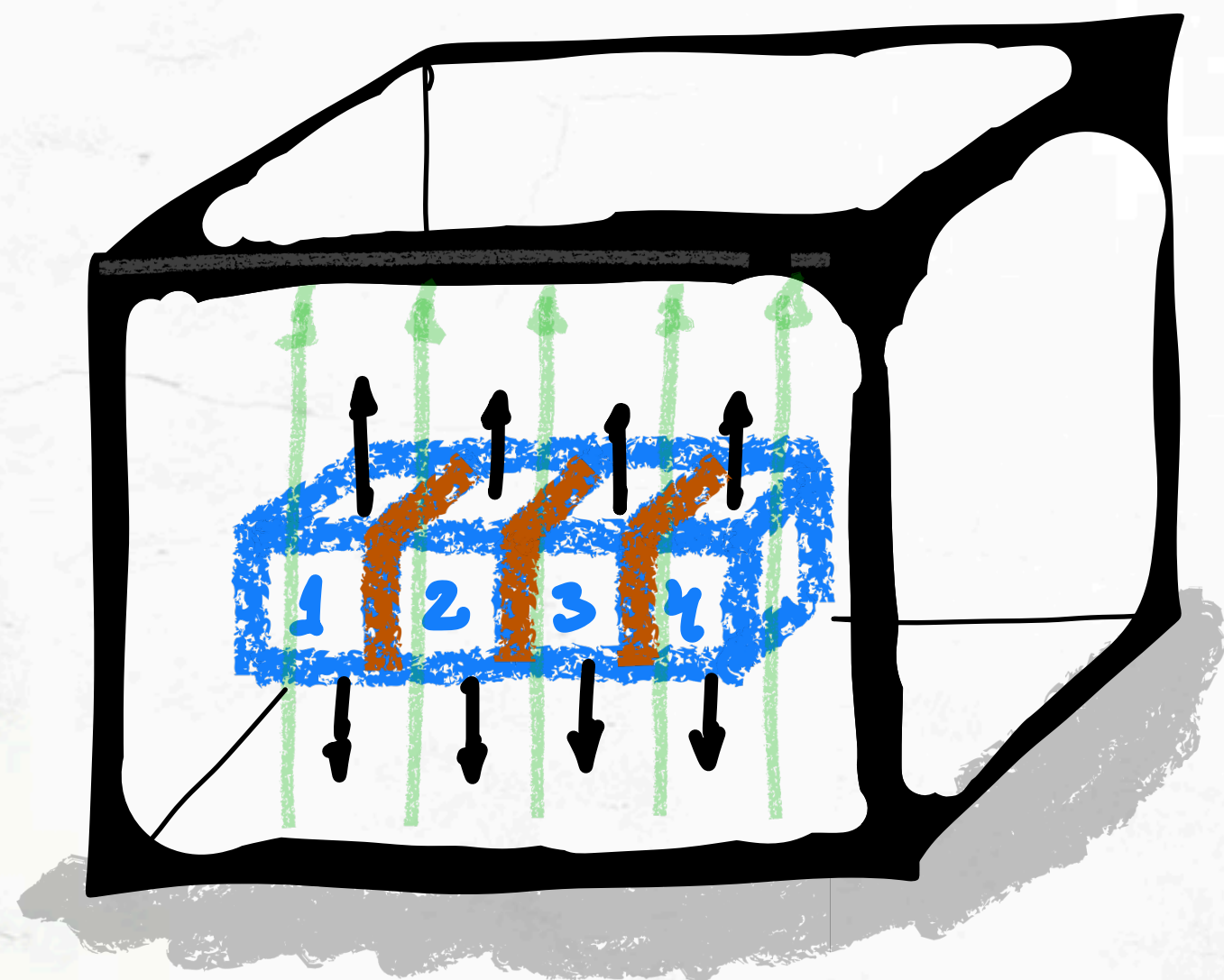
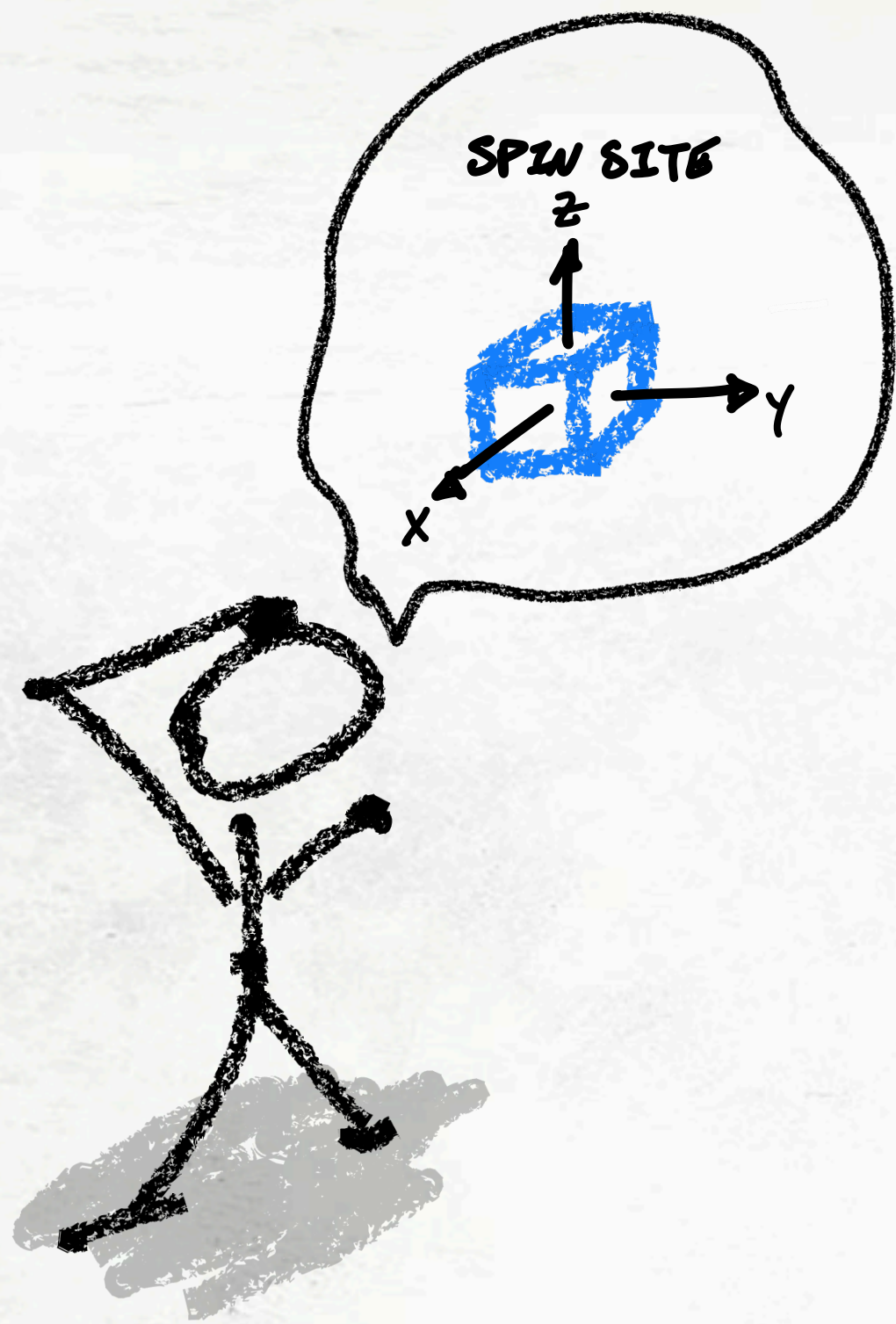
SPIN SITE

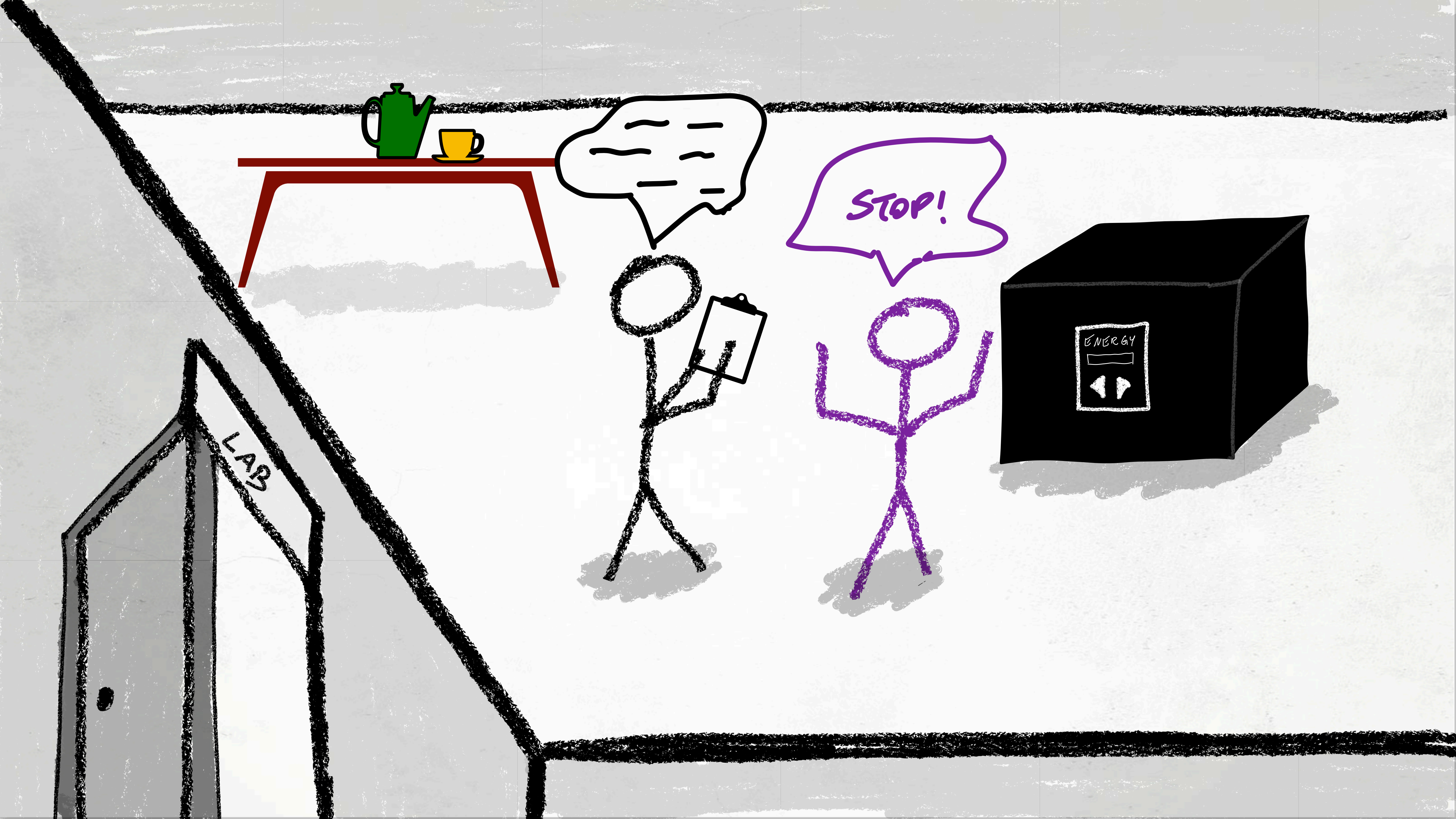


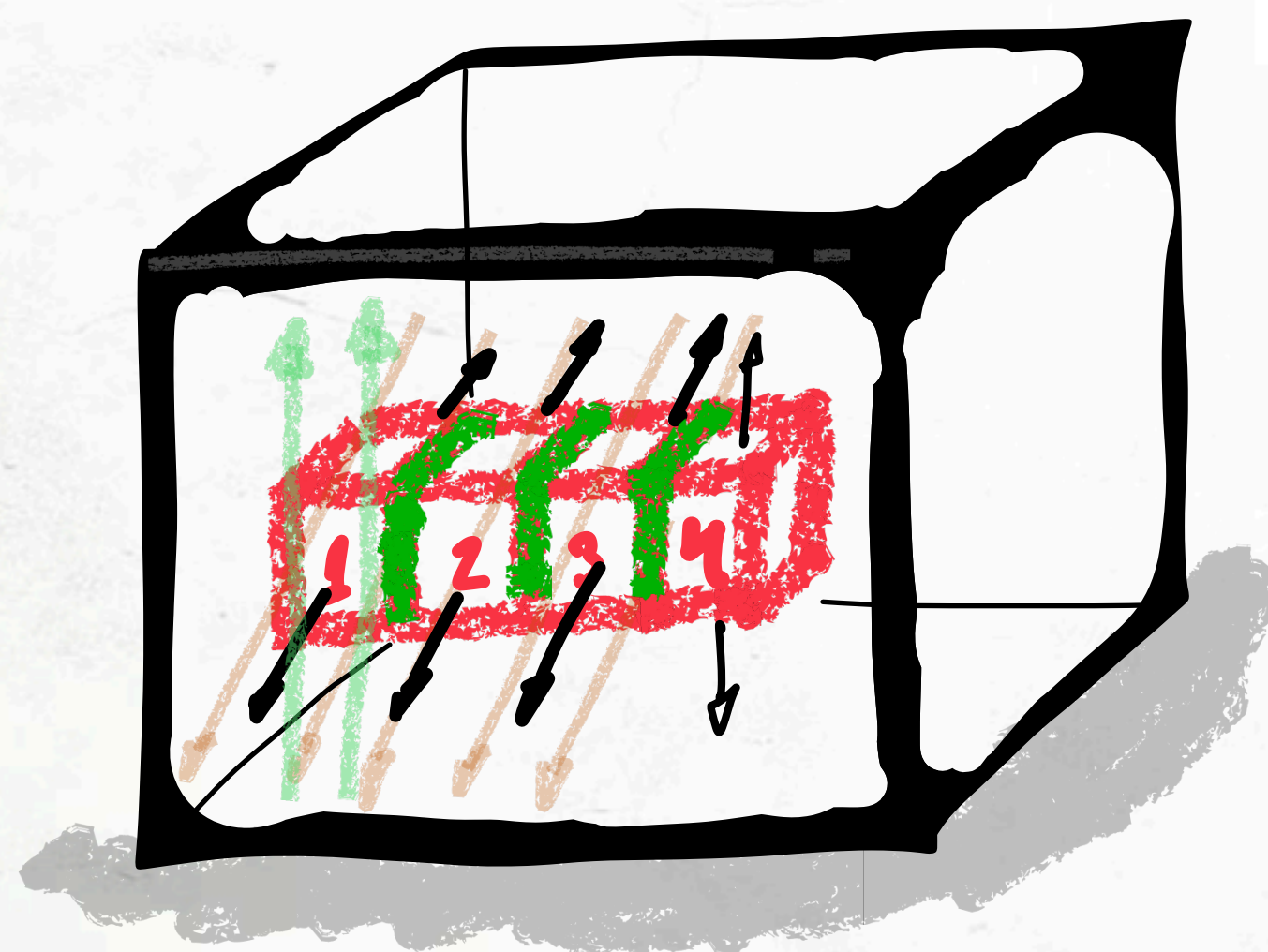
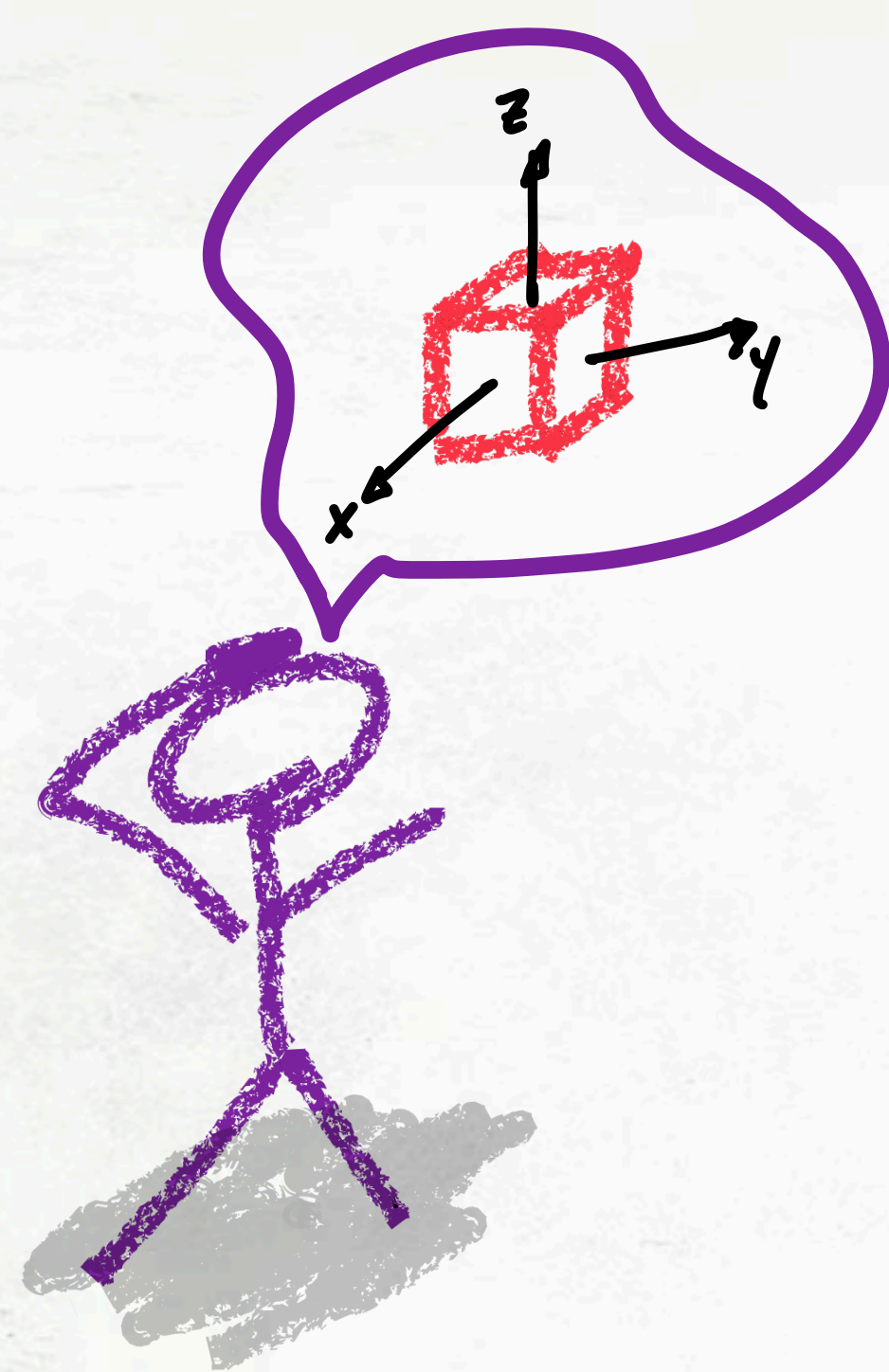
$$JS_1^z S_2^z$$



$$hS_4^z$$

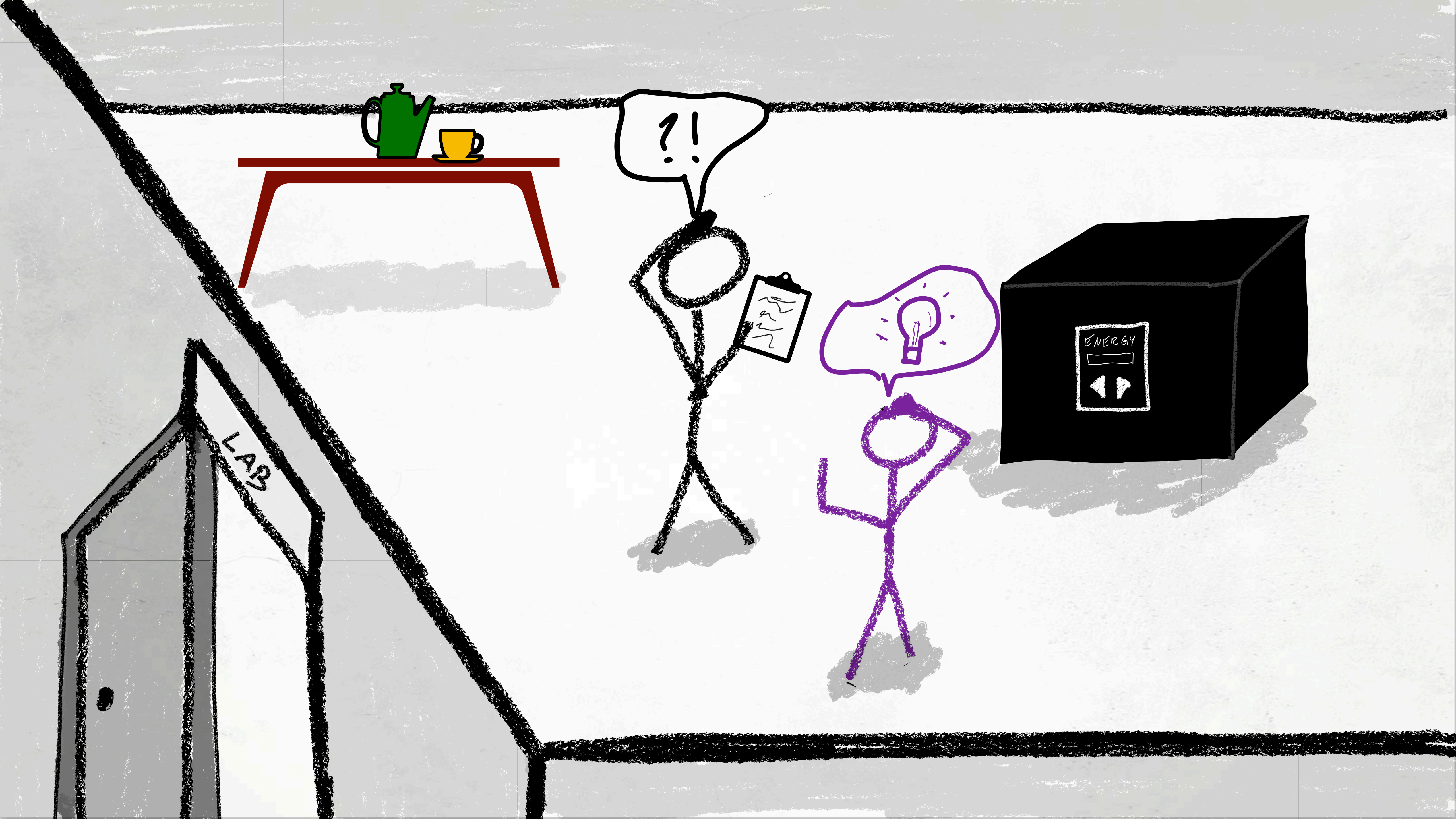




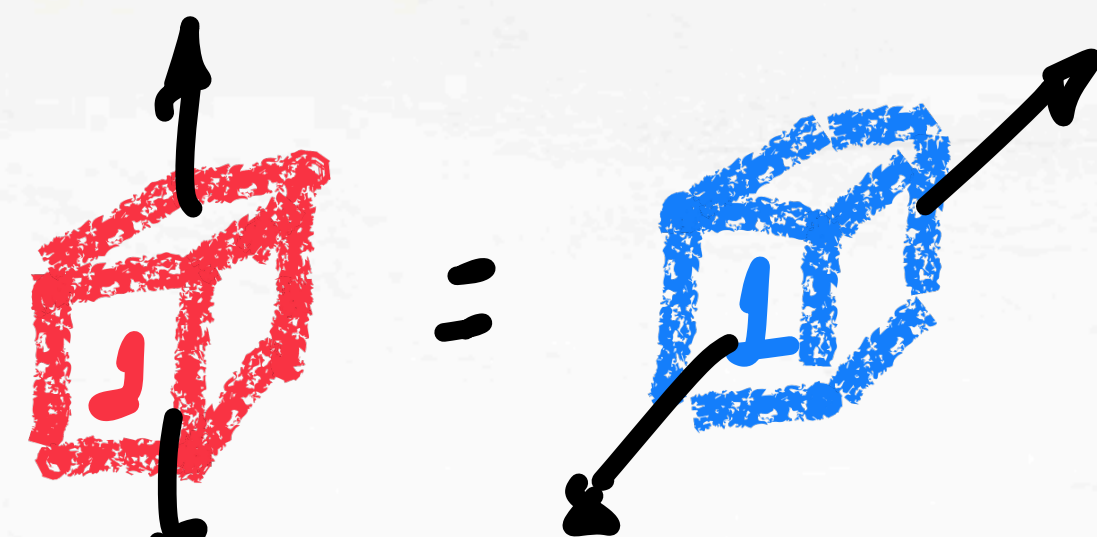


A large cloud-shaped box contains the following sum of energy terms:

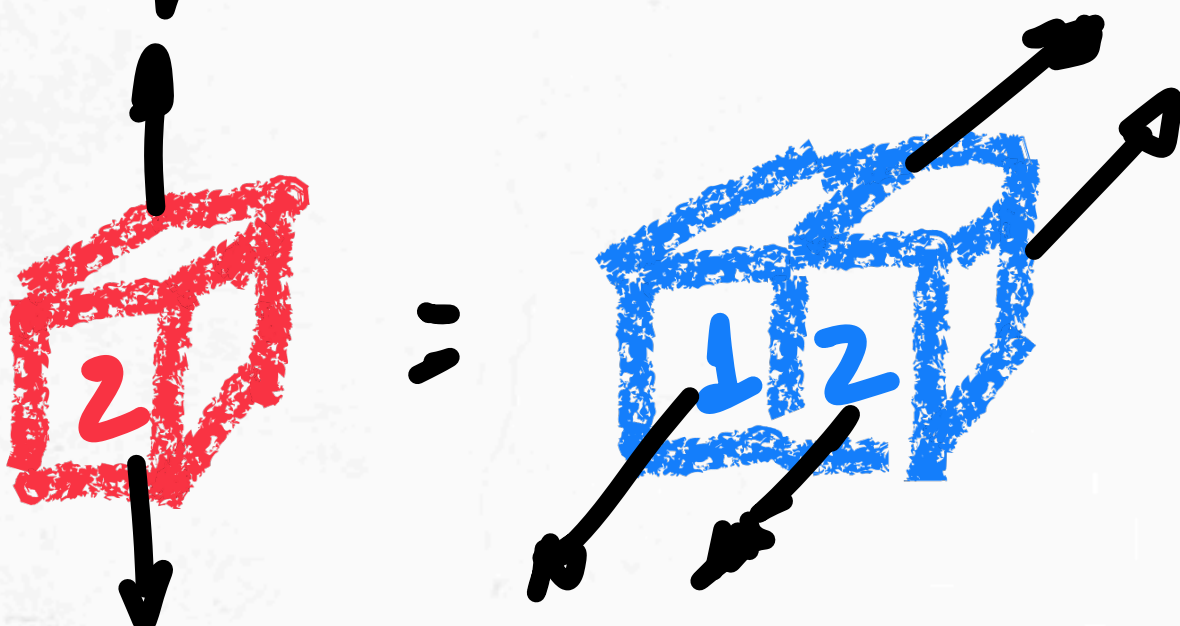
$$\begin{aligned}
 & \left(\begin{array}{c} \text{Red cube with cells 1, 2} \\ \uparrow \uparrow \\ hU_1^z U_2^z \\ \downarrow \downarrow \end{array} \right) + \left(\begin{array}{c} \text{Red cube with cells 2, 3} \\ \uparrow \uparrow \\ hU_2^z U_3^z \\ \downarrow \downarrow \end{array} \right) + \left(\begin{array}{c} \text{Red cube with cells 3, 4} \\ \uparrow \uparrow \\ hU_3^z U_4^z \\ \downarrow \downarrow \end{array} \right) \\
 & + \left(\begin{array}{c} \text{Red wireframe cube with cells 1, 2, 3} \\ \text{Brown arrows} \\ J(U_1^x + U_2^x + U_3^x) \end{array} \right) + \left(\begin{array}{c} \text{Red cube with cell 1} \\ \text{Green arrows} \\ hU_1^z \\ \downarrow \end{array} \right) = \text{ENERGY}
 \end{aligned}$$



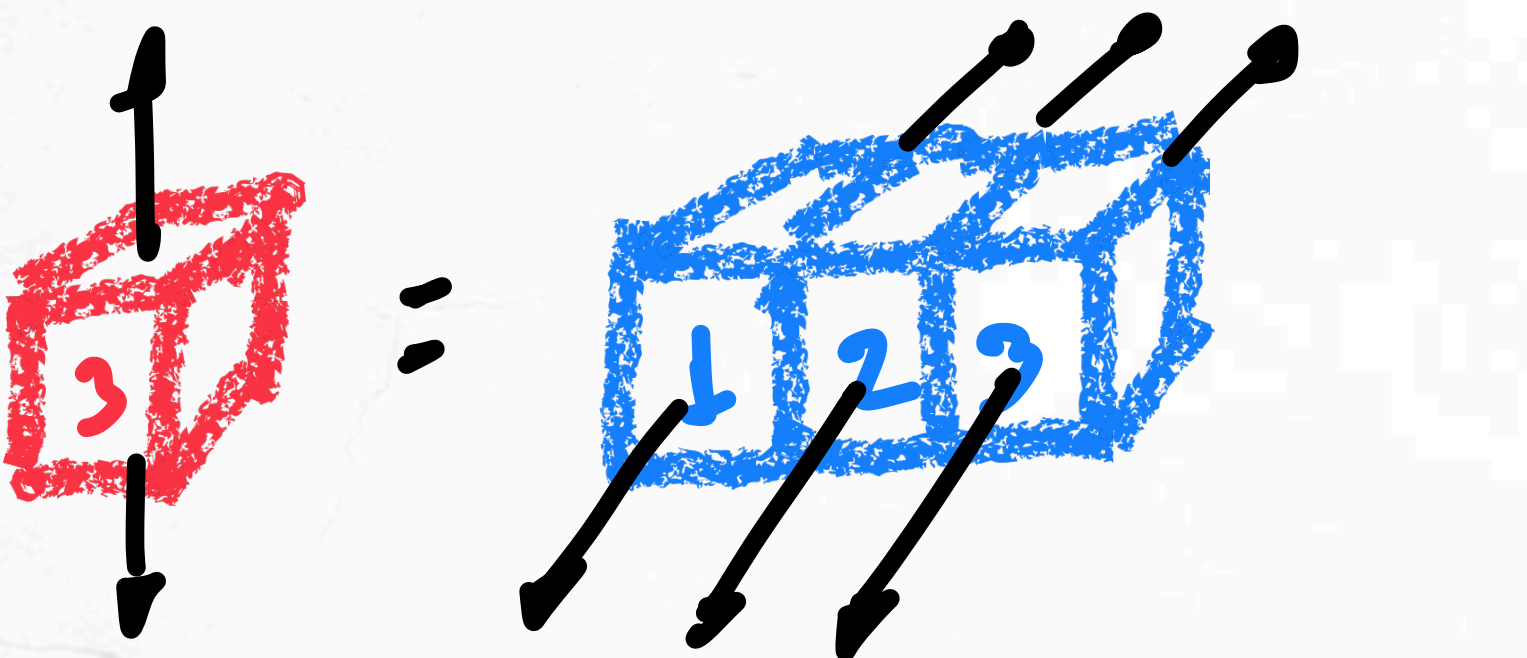
$$U_1^z = S_1^x$$



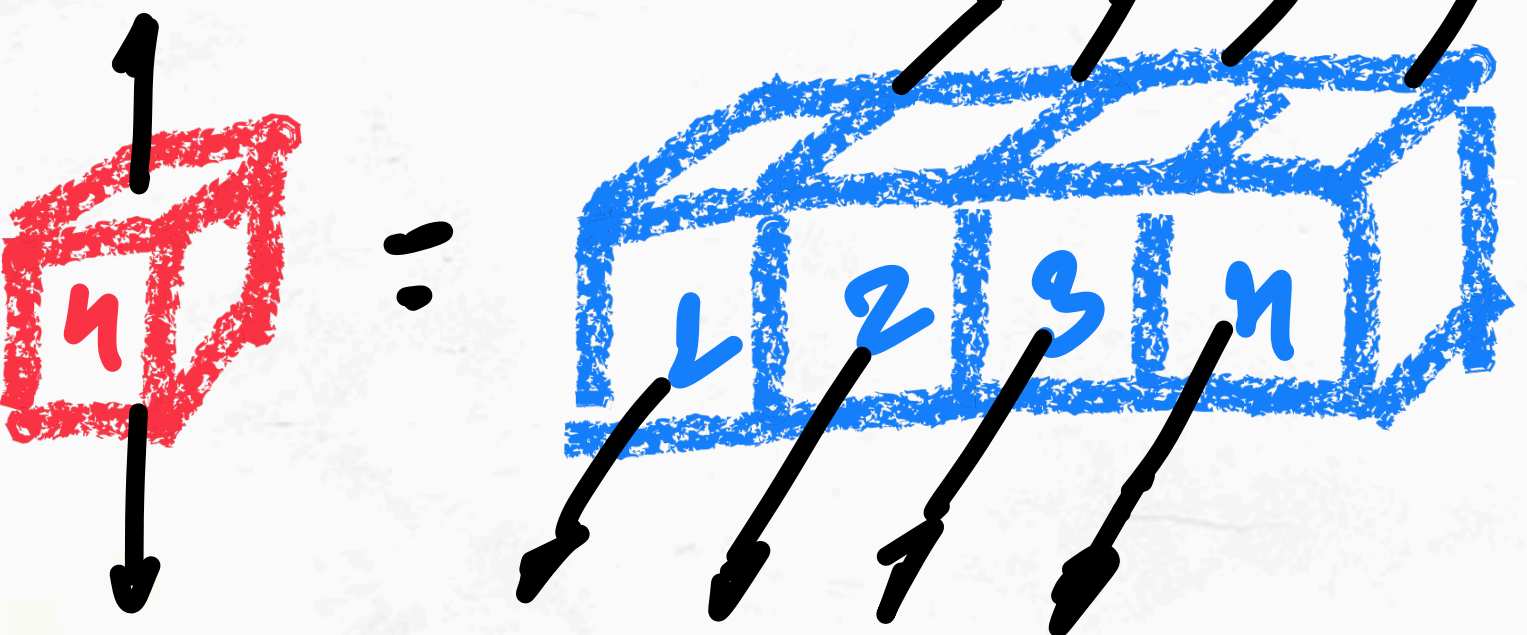
$$U_2^z = S_1^x S_2^x$$



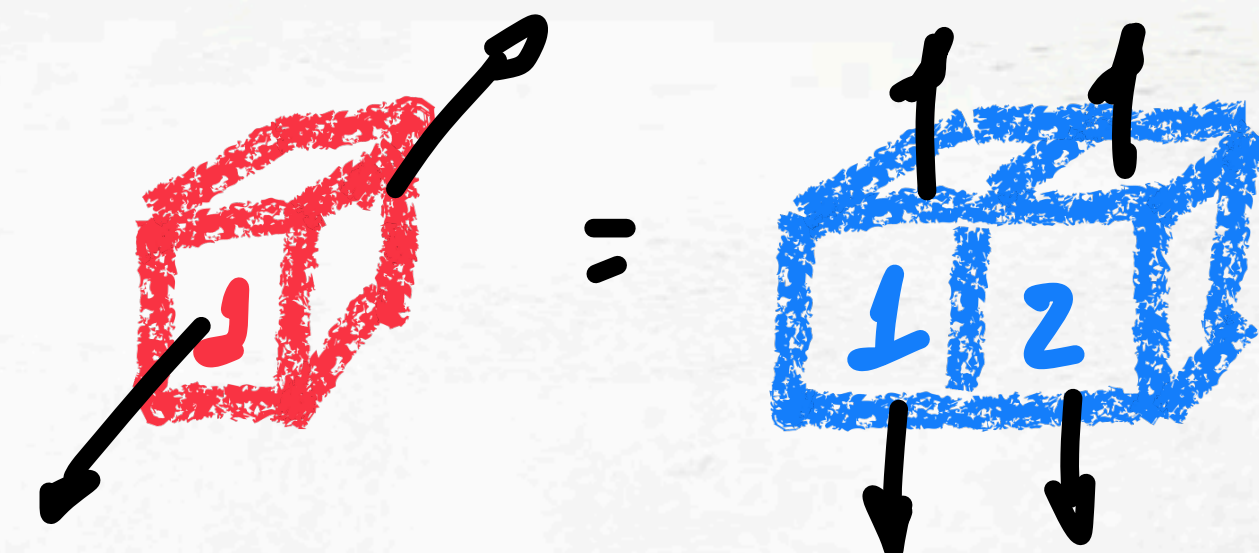
$$U_3^z = S_1^x S_2^x S_3^x$$



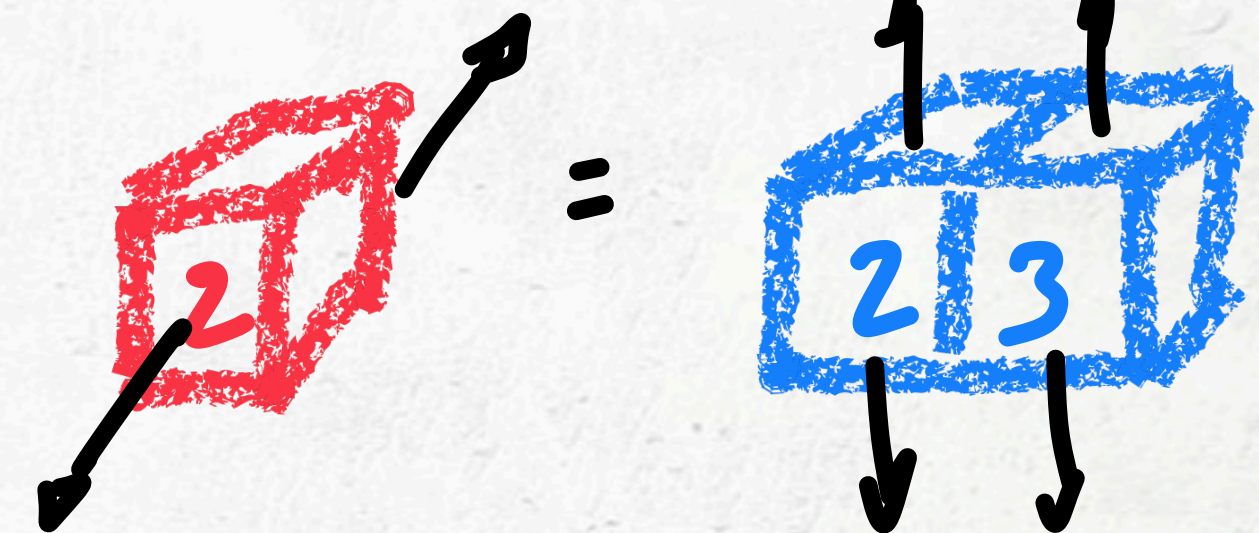
$$U_4^z = S_1^x S_2^x S_3^x S_4^x$$



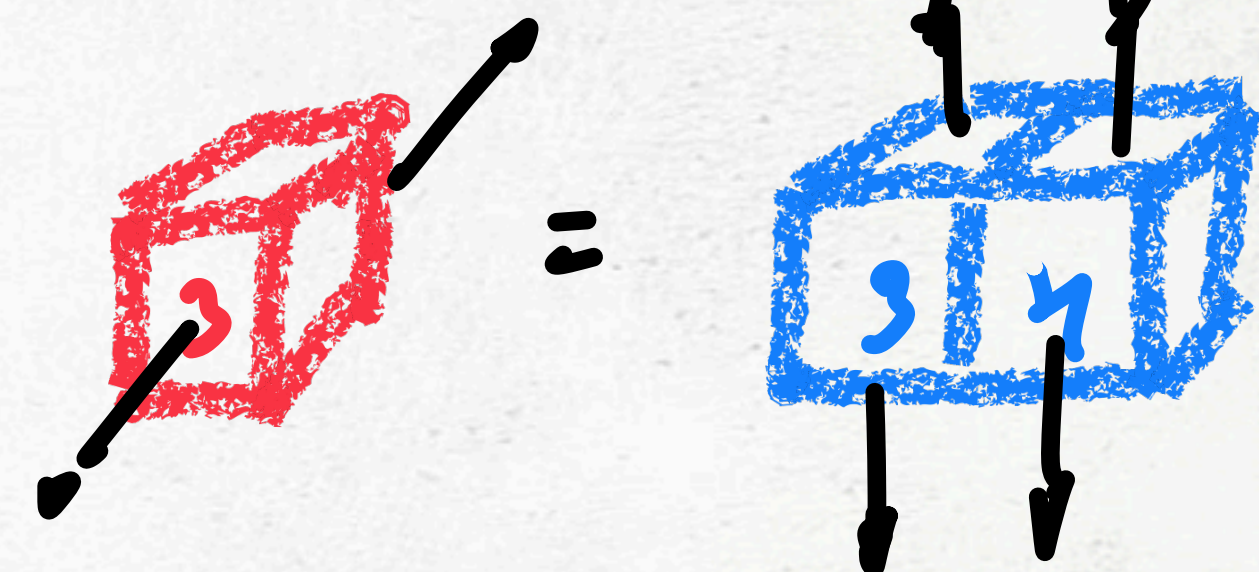
$$U_1^x = S_1^z S_2^z$$



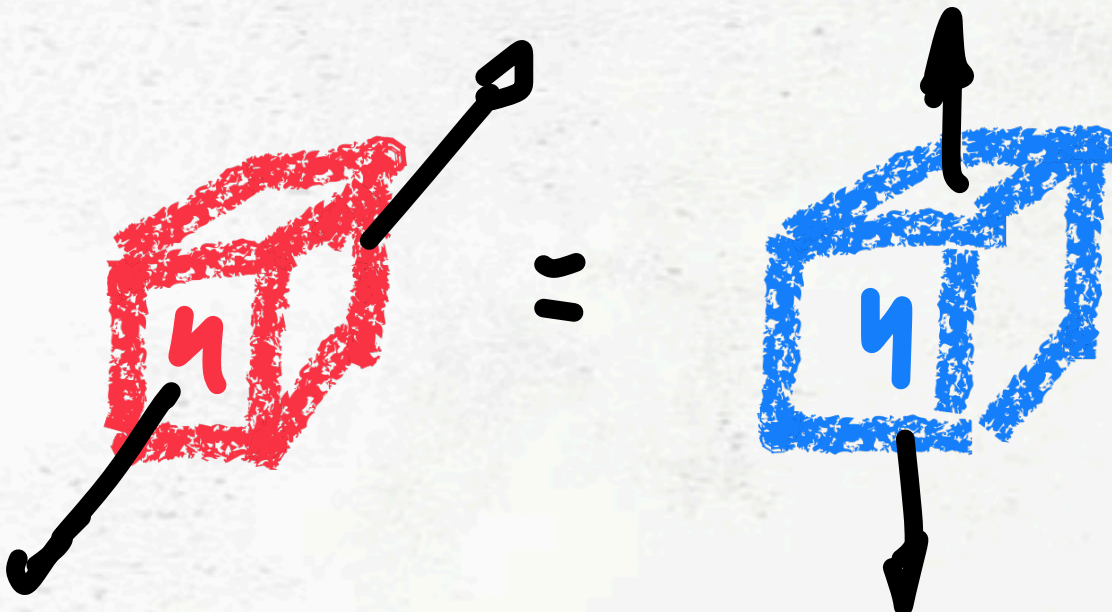
$$U_2^x = S_2^z S_3^z$$



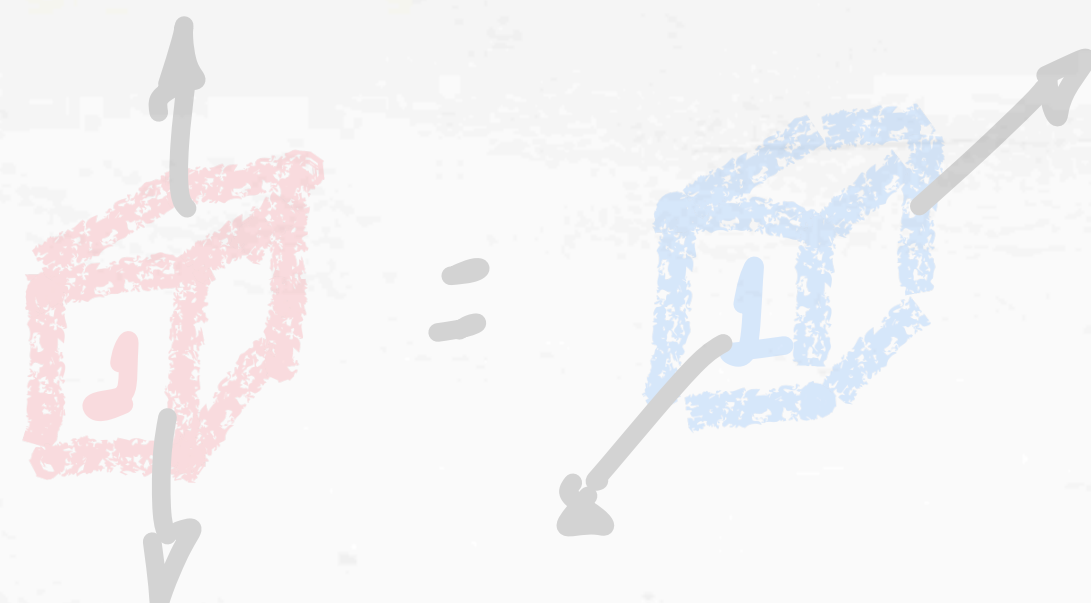
$$U_3^x = S_3^z S_4^z$$



$$U_4^x = S_4^z$$



$$U_1^z = S_1^x$$



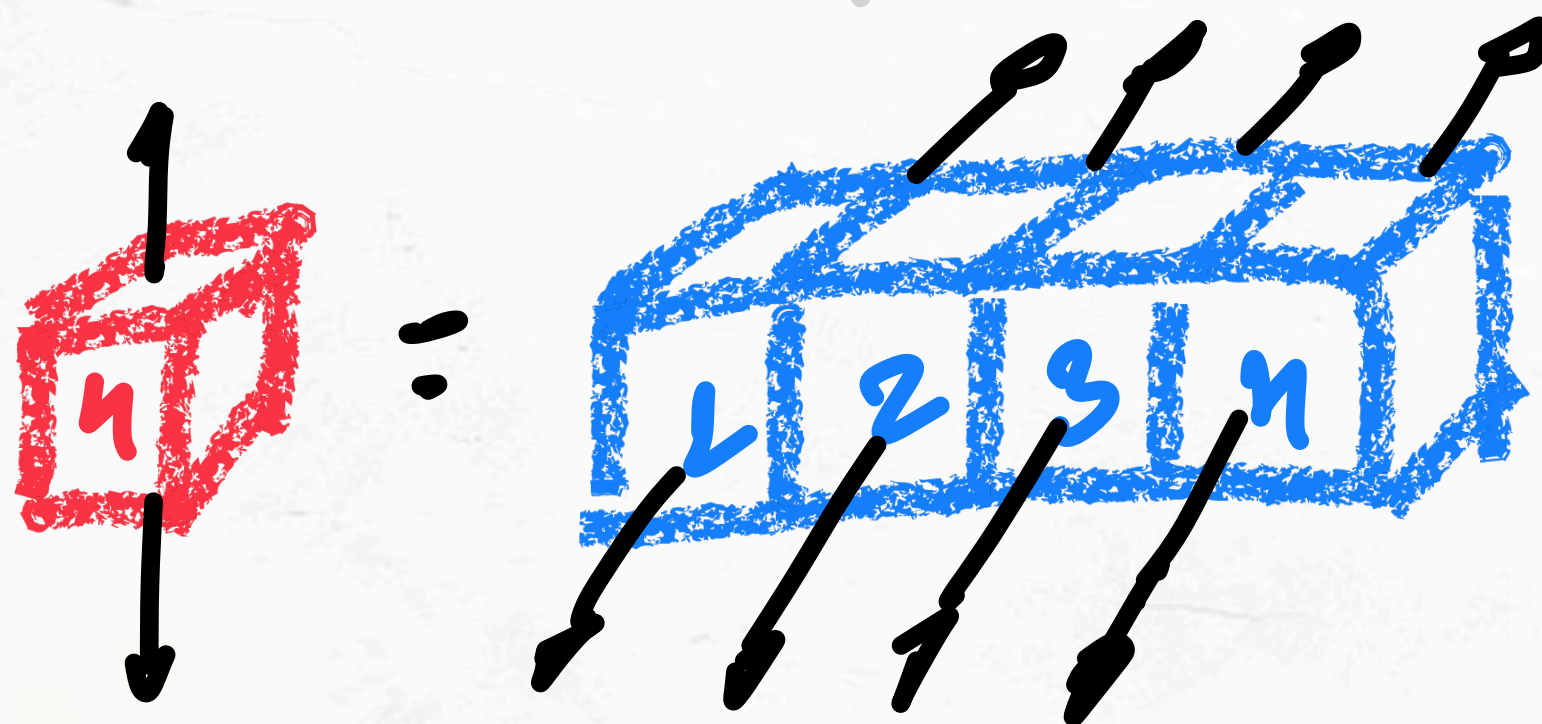
$$U_2^z = S_1^x S_2^x$$



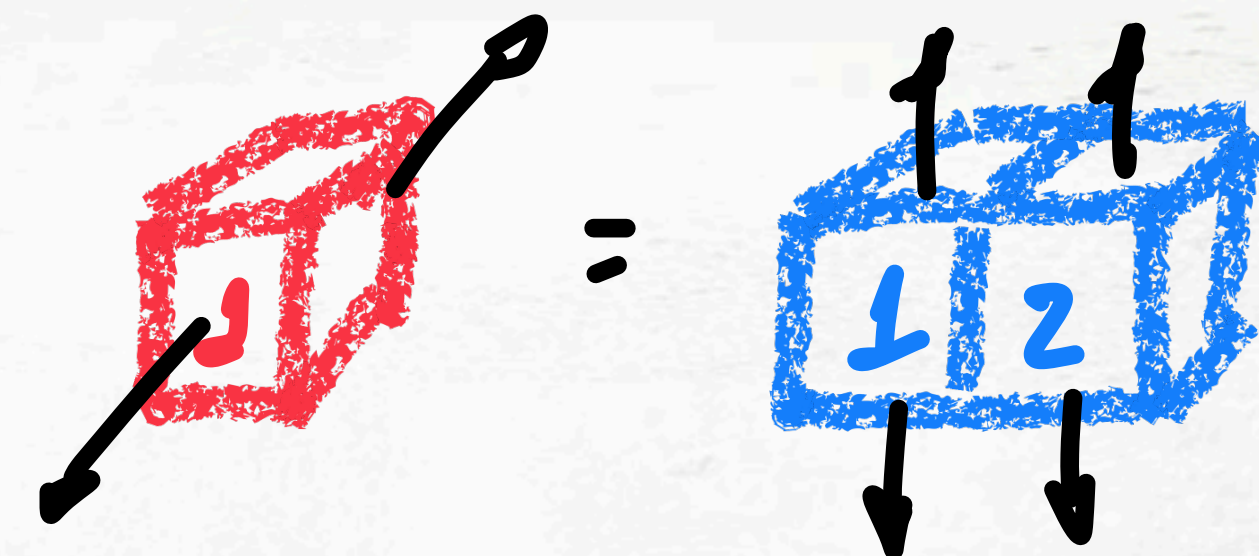
$$U_3^z = S_1^x S_2^x S_3^x$$



$$U_4^z = S_1^x S_2^x S_3^x S_4^x$$



$$U_1^x = S_1^z S_2^z$$



$$U_2^x = S_2^z S_3^z$$



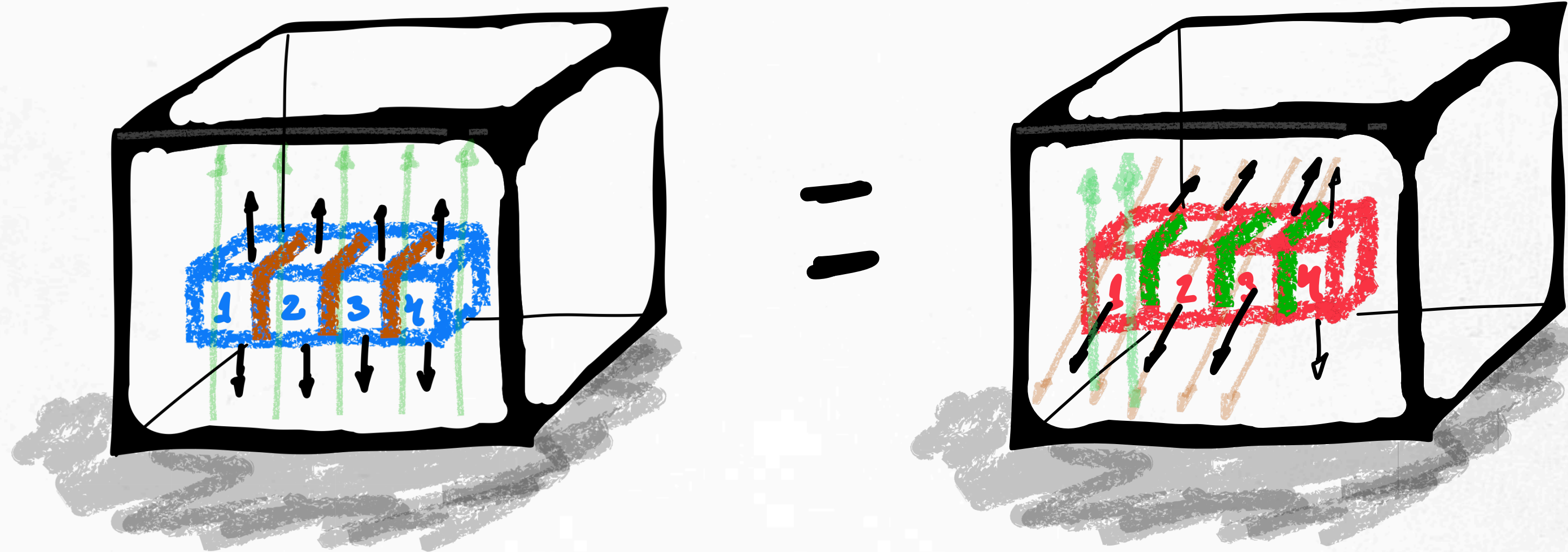
$$U_3^x = S_3^z S_4^z$$



$$U_4^x = S_4^z$$



Formally, this is called a **duality**.

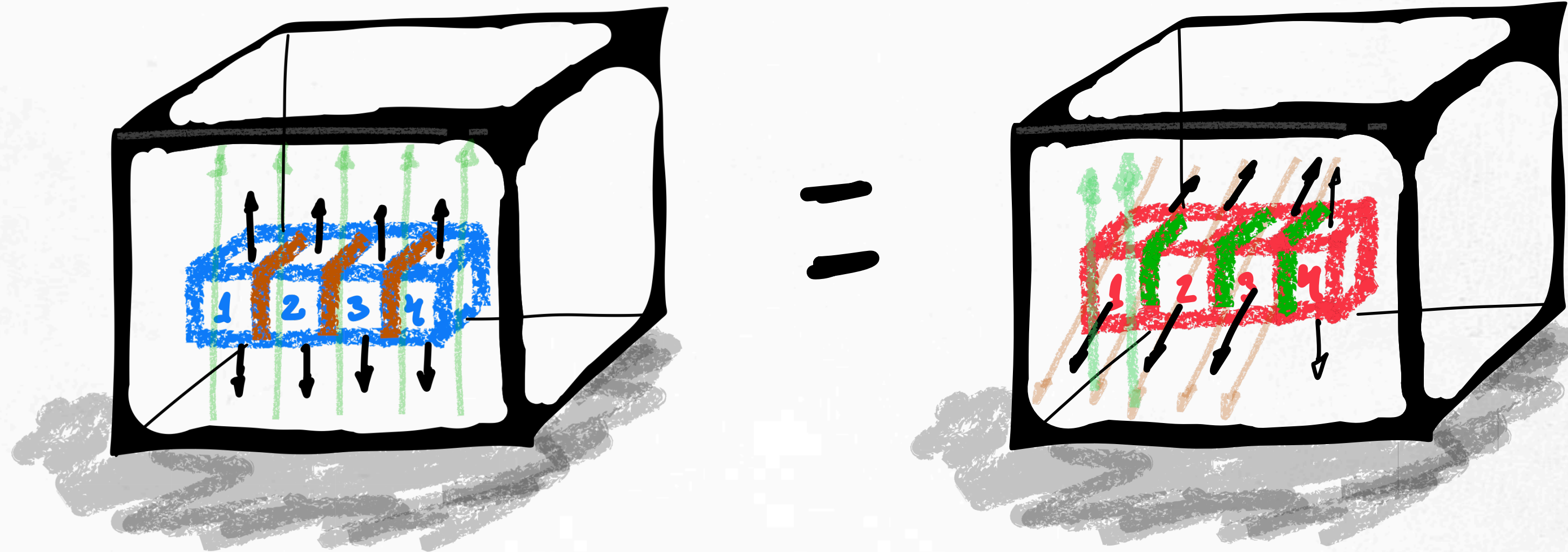


$$H = J \sum_{i=1}^{n-1} S_i^z S_{i+1}^z + h \sum_{i=1}^n S_i^z = J \sum_{i=1}^n U_i^x + h \sum_{i=1}^{n-1} U_i^z U_{i+1}^z - J U_n^x + h U_1^z$$

$$U_i^z = \prod_{j \leq i} S_j^x, \quad U_i^x = S_i^z S_{i+1}^z, \quad U_n^x = S_n^z$$

So, which one is it? How do we find out?

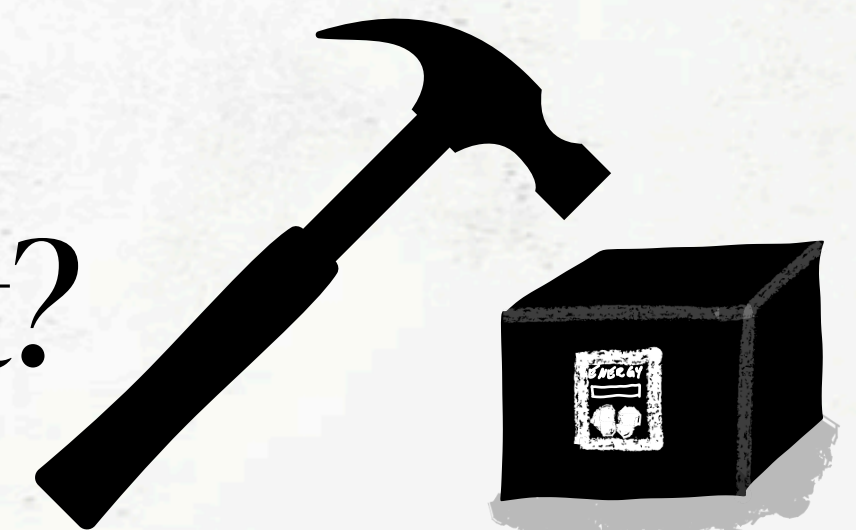
Formally, this is called a **duality**.



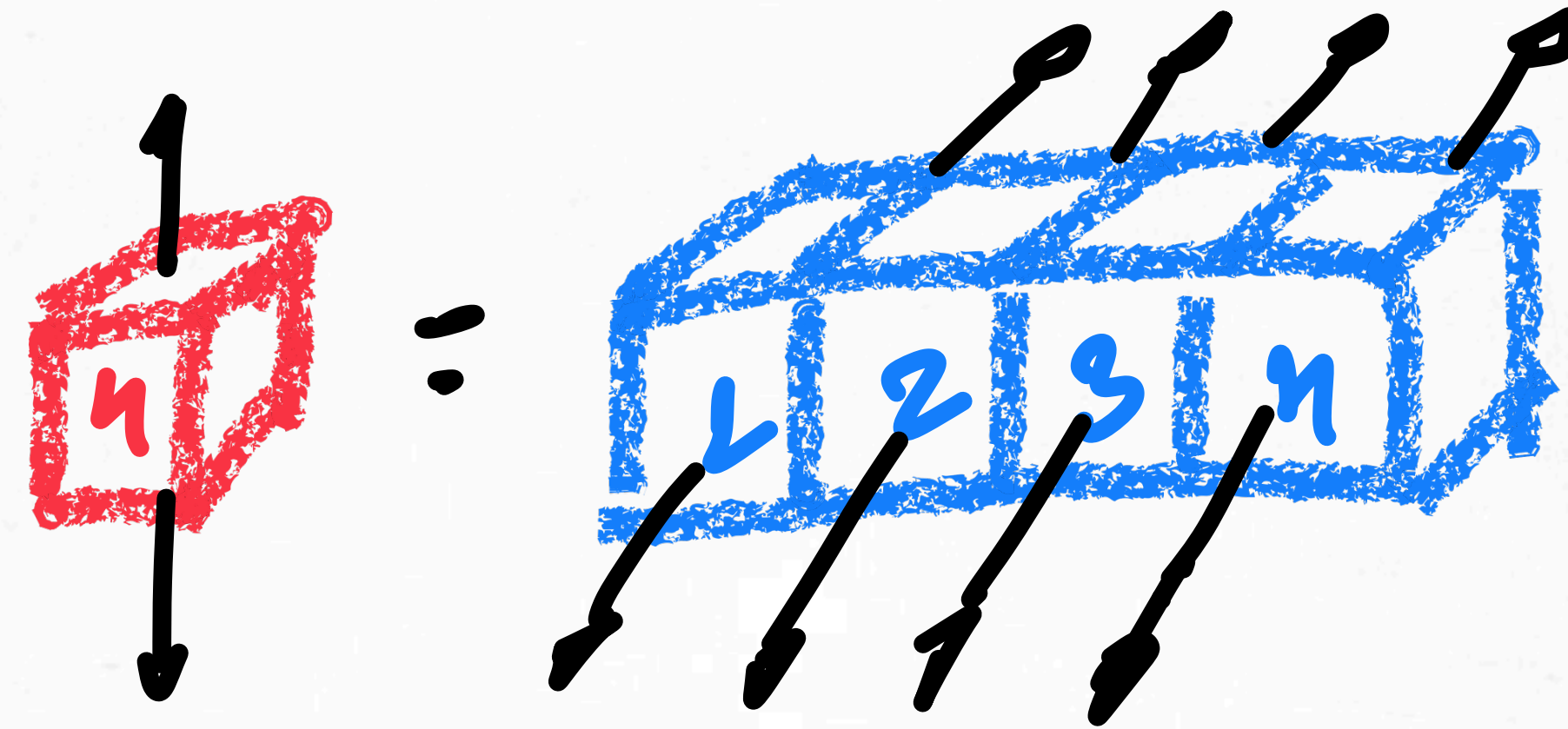
$$H = J \sum_{i=1}^{n-1} S_i^z S_{i+1}^z + h \sum_{i=1}^n S_i^z = J \sum_{i=1}^n U_i^x + h \sum_{i=1}^{n-1} U_i^z U_{i+1}^z - J U_n^x + h U_1^z$$

$$U_i^z = \prod_{j \leq i} S_j^x, \quad U_i^x = S_i^z S_{i+1}^z, \quad U_n^x = S_n^z$$

So, which one is it? How do we find out?



What if you cannot open the box?



We see that each description of what's inside assumes a different notion of the system, different notion of which parts are interacting, and therefore different notion of what's a neighboring site!

How do we make sense of that?

Side quest:

Ask a philosopher!

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Logic and Ontology

First published Mon Oct 4, 2004; substantive revision Mon Mar 13, 2023

A number of important philosophical problems are at the intersection of logic and ontology. Both logic and ontology are diverse fields within philosophy and, partly because of this, there is not one single philosophical problem about the relation between them. In this survey article we will first discuss what different philosophical projects are carried out under the headings of “logic” and “ontology” and then we will look at several areas where logic and ontology overlap.

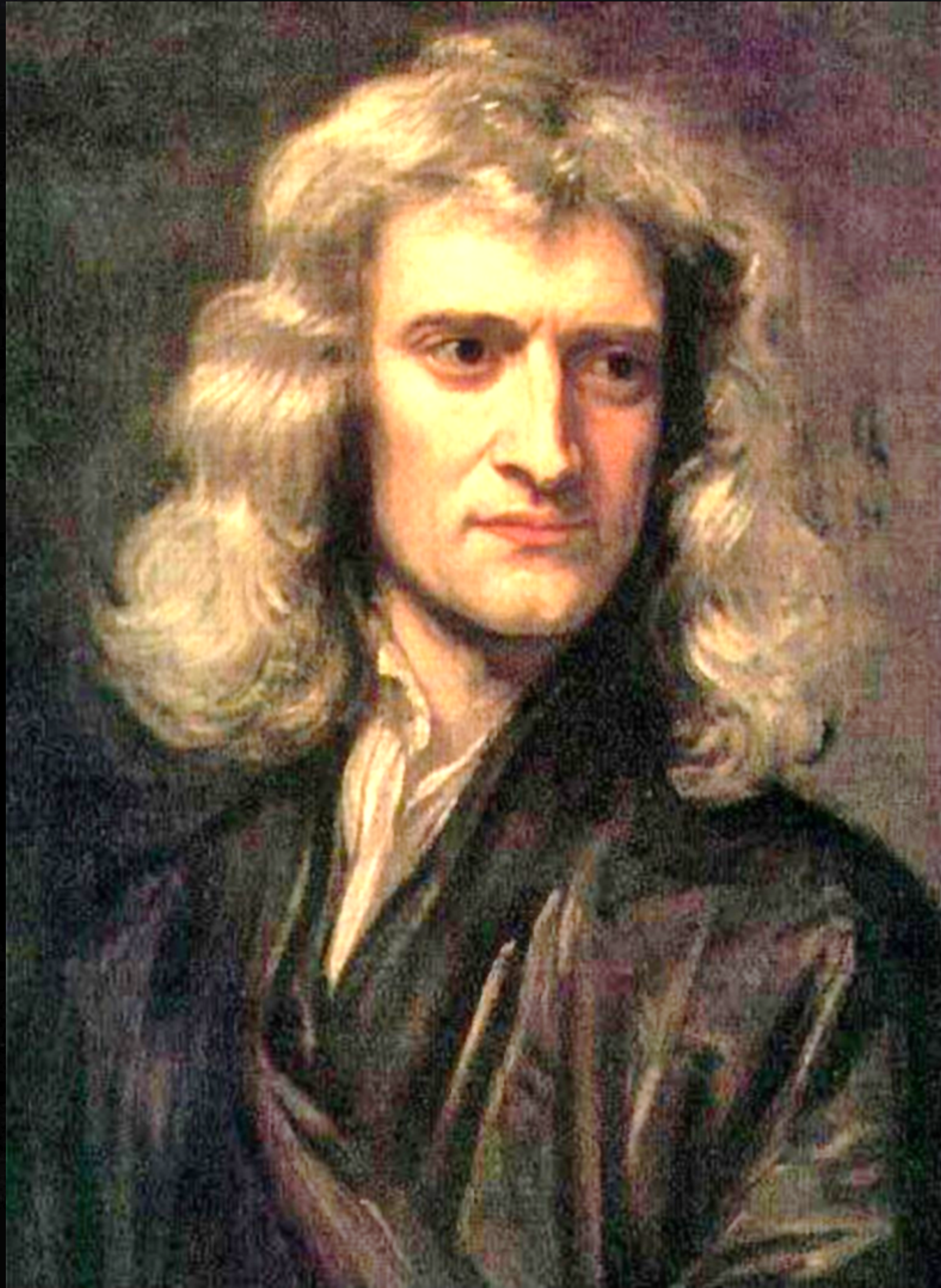


3. Ontology

3.1 Different conceptions of ontology

As a first approximation, ontology is the study of what there is. Some contest this formulation of what ontology is, so it's only a first approximation. Many classical philosophical problems are problems in ontology: the question whether or not there is a god, or the problem of the existence of universals, etc.. These are all problems in ontology in the sense that they deal with whether or not a certain thing, or more broadly entity, exists. But ontology is usually also taken to encompass problems about the most general features and relations of the entities which do exist. There are also a number of classic philosophical problems that are problems in ontology understood in this way. For example, the problem of how a universal relates to a particular that has it (assuming there are universals and particulars), or the problem of how an event like John eating a cookie relates to the particulars John and the cookie, and the relation of eating, assuming there are events, particulars and relations. These kinds of problems quickly turn into metaphysics more generally, which is the philosophical discipline that encompasses ontology as one of its parts. The borders here are a little fuzzy. But we have at least two parts to the overall philosophical project of ontology, on our preliminary understanding of it: first, say what there is, what exists, what the stuff of reality is made out of, secondly, say what the most general features and relations of these things are.

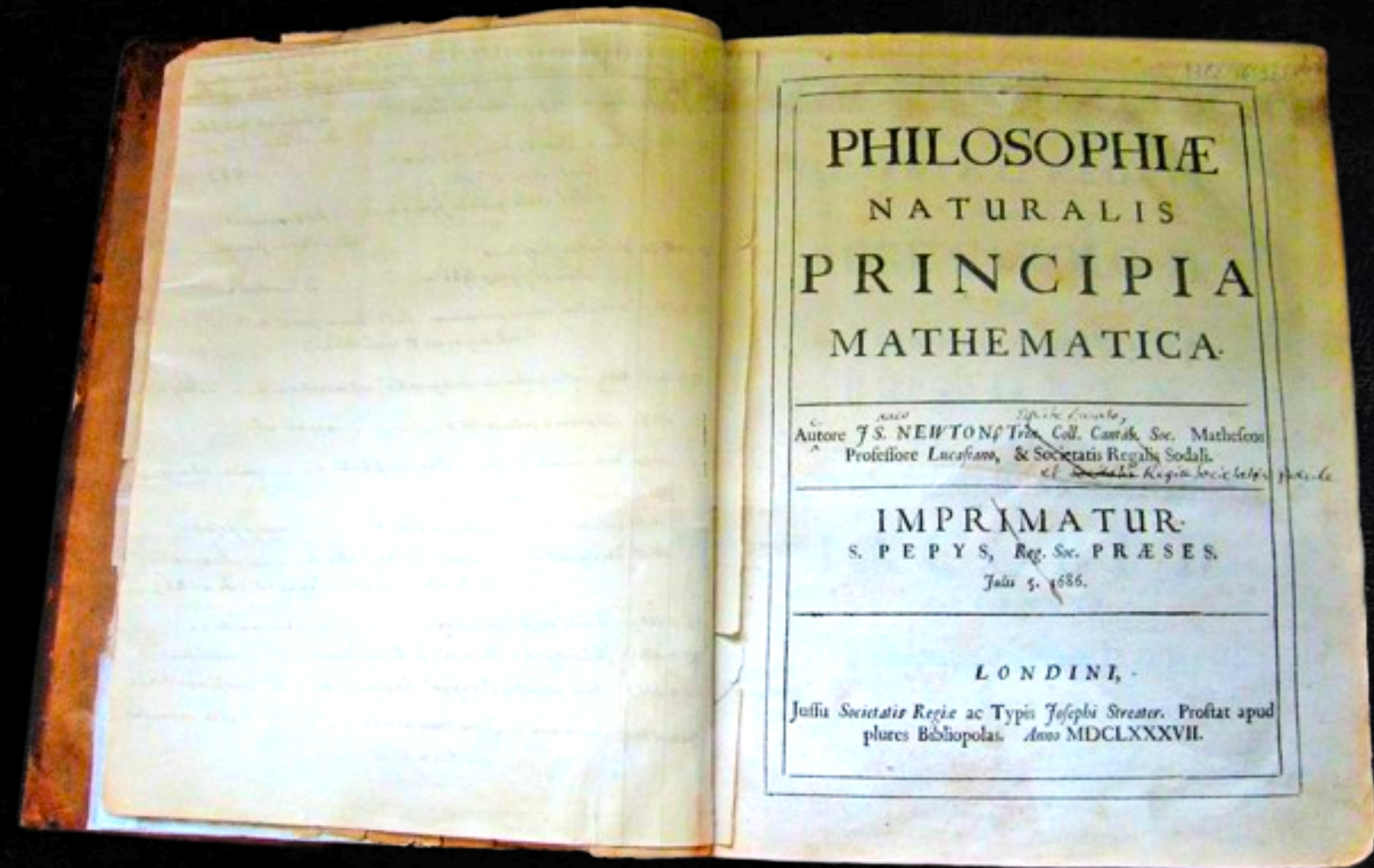
Chapter 2: Classical Mechanics



(BOOK I)

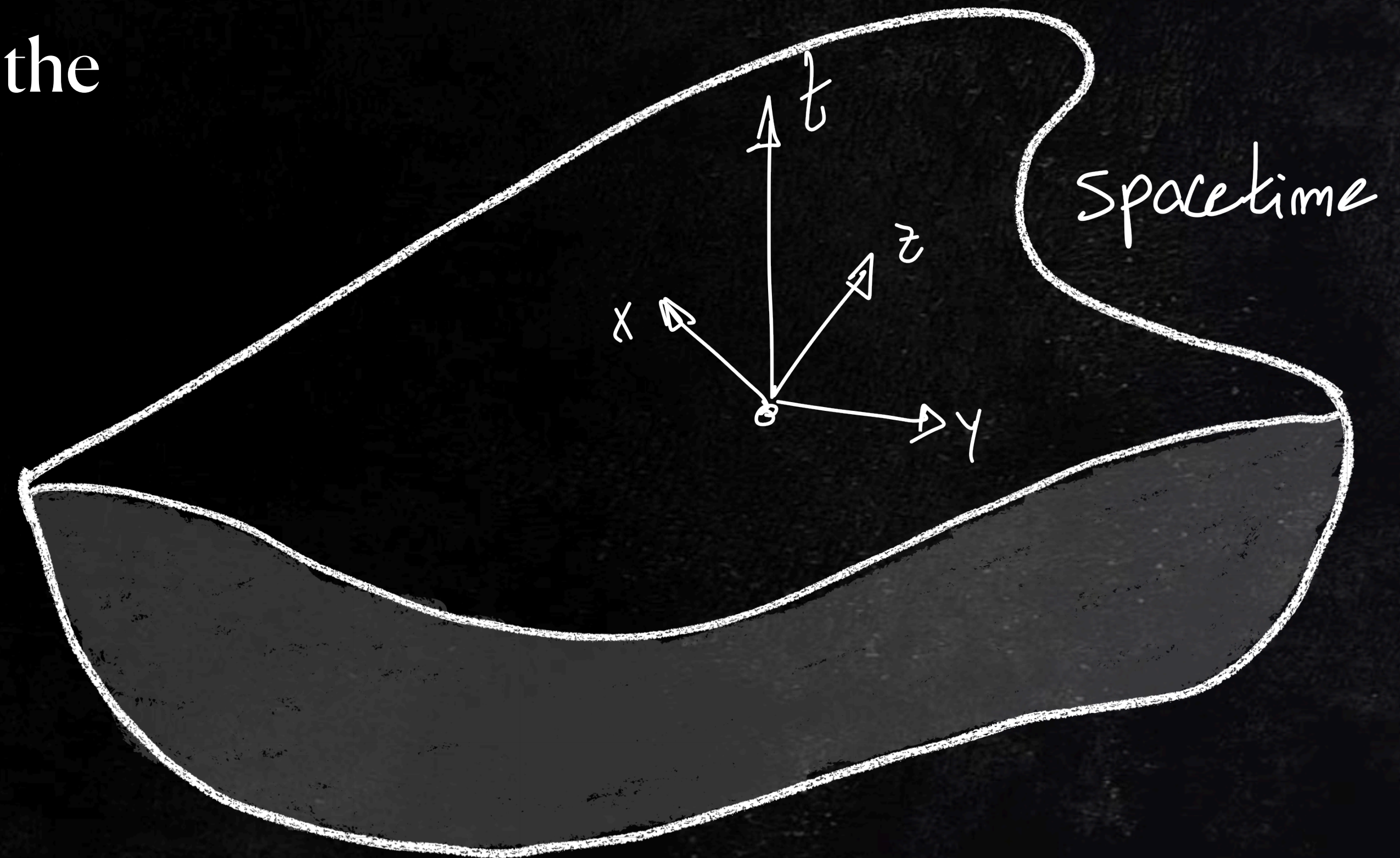
"I. **Absolute**, true, and mathematical **time**, of itself, and from its own nature, flows equably *without* relation to anything external."

"II. **Absolute space**, in its own nature, *without* regard to anything external, remains always similar and immovable."

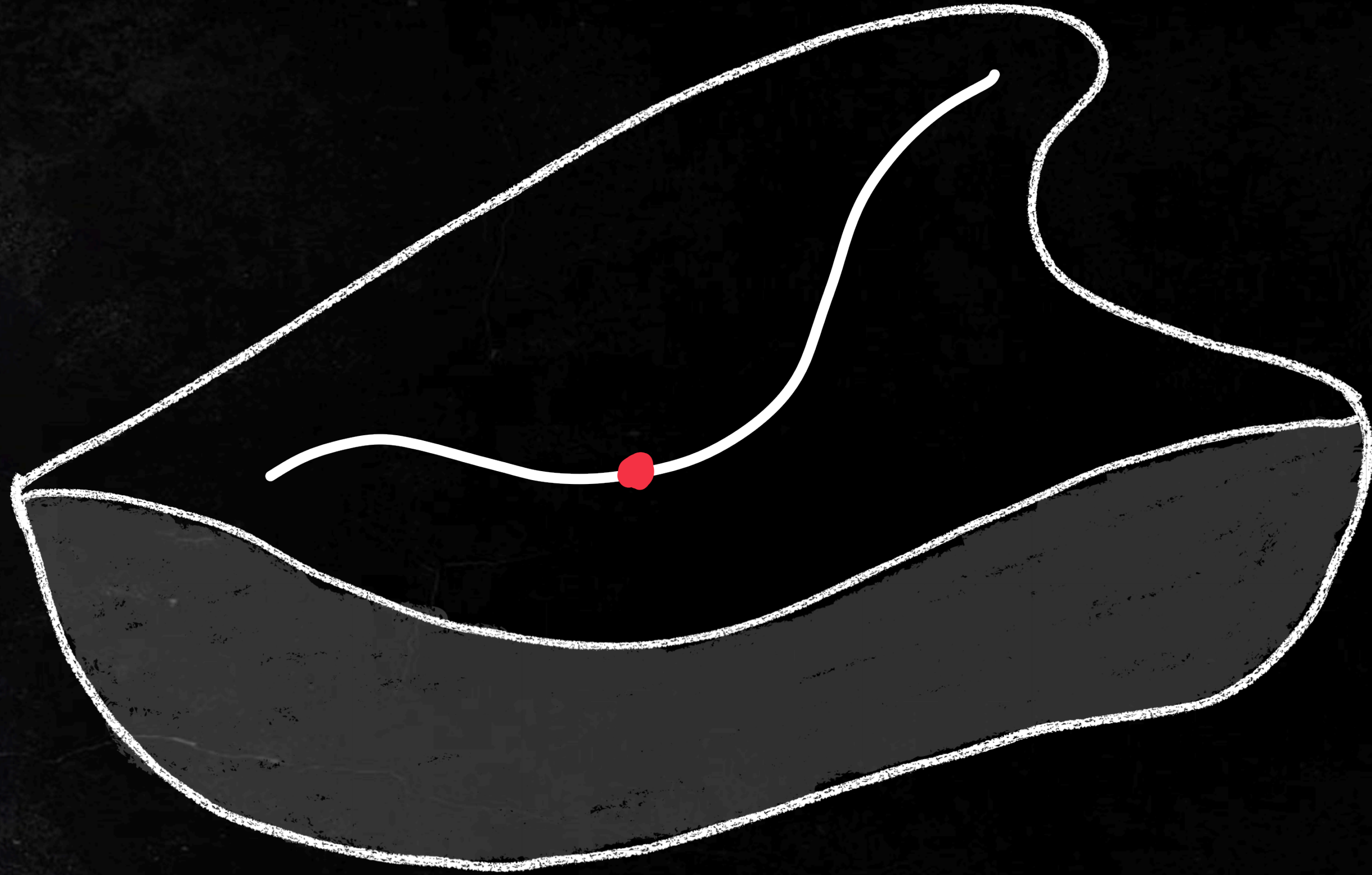


Substantivalism:

Space and time **exist** as *independent* substances, i.e., independently of the material content of the universe.



But so there is also material content!
Let's consider a particle:



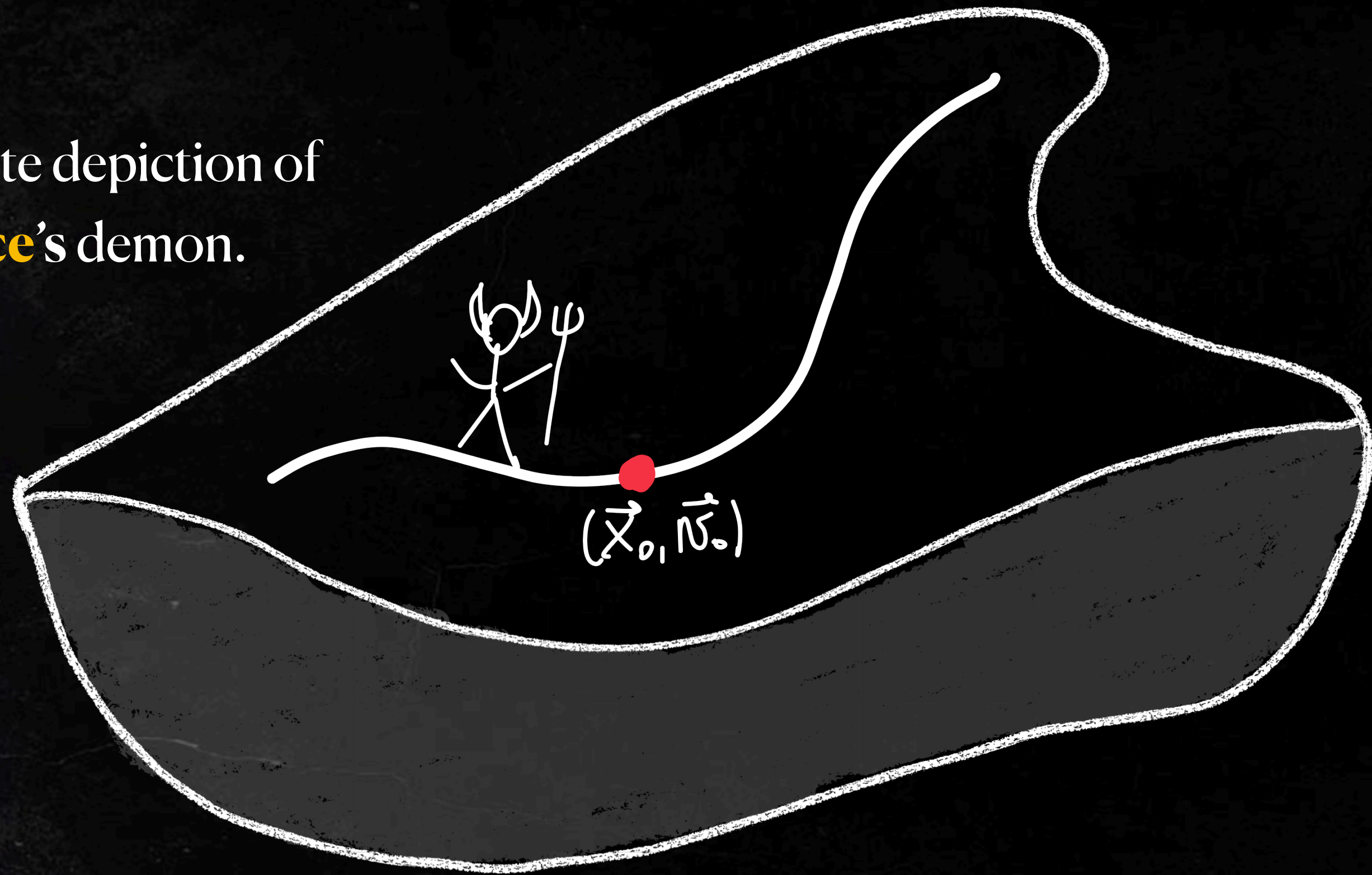
a) A state: $(\vec{x}, \vec{v})$

b) An evolution equation*:

$$\vec{F}(\vec{x}) = m \frac{d^2 \vec{x}}{dt^2}$$

(*Generally, non-linear equation)

Accurate depiction of
Laplace's demon.



Classical mechanics is deterministic!



Center of Mass Motion

10^{50} particles in the Earth $\rightarrow$ positions and velocities
for each of them

But, the center of mass has only 6 “degrees of
freedom”: its $\vec{r}$ -position and $\vec{v}$ -velocity!

And still satisfies the *same* equations of motion!



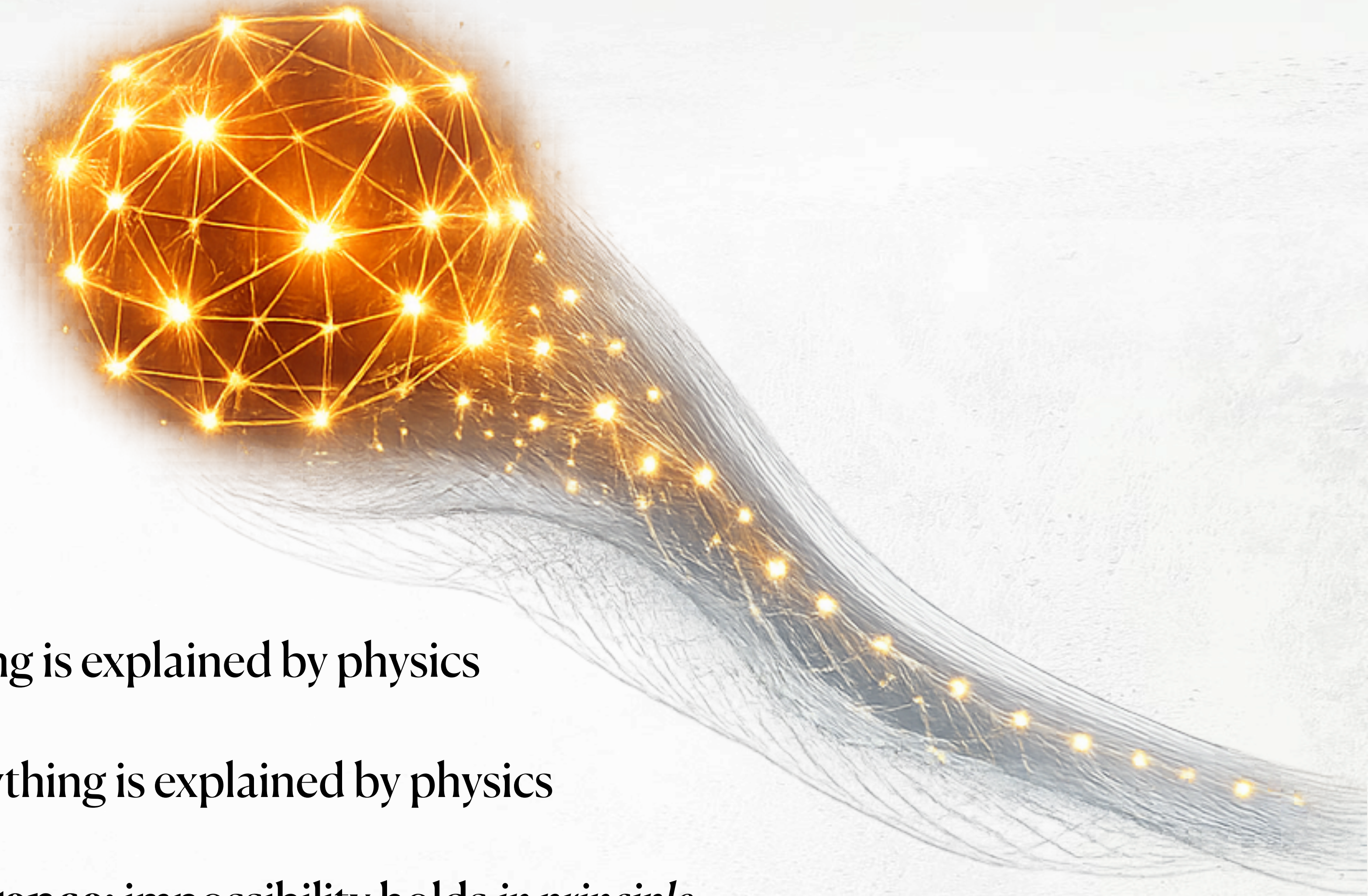


Chapter 3: A Tale of Emergence

Epistemological Stances

We have different choices:

- 1) **Reductionism:** everything is explained by physics
- 2) **Emergentism:** not everything is explained by physics
 - a) **strong emergence:** impossibility holds *in principle*
 - b) **weak emergence:** impossibility holds *in practice*





Understood as the appearance, in a certain description of a physical system, of properties that are **novel** with respect to a different (more ‘fundamental’) description of the same system, and **robust**, thus stable enough to represent a characterization of the new description and to form part of **new predictions** stemming from it.

Emergence, in this understanding, usually requires the use of **some limiting procedure** and of a number of **(possibly drastic) approximations**, to allow the novel properties to become visible in the new description.

| Emergence:

THE NATURE OF PHYSICAL THEORY
P. W. Bridgman

Written by a Nobel prize winner, one of the leading mathematical physicists of our time, this book is a penetrating study of modern scientific theory which offers unusual insight into the problem of correlating reality with the various theoretical structures set up in the past fifty years. It analyzes the inadequacies of physical theories in supplying the answers to all questions, but points out the real service these concepts render within limited frames of reference.

Skillfully the author investigates and weighs the contributions of Newton, Bohr, Einstein, Heisenberg and other outstanding scientists. He discusses with rare objectivity such basic concepts as the wave and corpuscular theories, the "clocks" of relativity, the "laws" of probability, the mathematical system itself, and reaches conclusions of such validity and importance to make the work extremely lucid and absorbing.

"It can easily be read in about three hours, but it will then demand to be re-read, parts of it several times over... how refreshing it is to find a man of undoubted eminence actually asking and insisting upon certain simple queries such as have been repressed for so long by the extraordinary ascendancy which a few theoretical physicists of the most exact type have attained over the rest of the community. The style is clear, eloquent and vocabulary rich and in Review of

- Stage Space
- Degrees of Freedom
- Observables
- Dynamical Equations

Emergence - Level 0

Space Stage

Degrees of
Freedom

Observables

Dynamical
Equations

•
•

$\mathcal{M}$

10^{50} of $(\vec{x}, \vec{p})$'s

$f_a(\vec{x}_I, \vec{v}_I)$

$$\vec{F}(\vec{x}_I) = m_I \frac{d\vec{v}_I}{dt}$$



$\mathcal{M}$

$(\vec{x}_{\text{CM}}, \vec{p}_{\text{CM}})$

$f_a(\vec{x}_{\text{CM}}, \vec{v}_{\text{CM}})$

$$\vec{F}(\vec{x}_{\text{CM}}) = m_{\text{CM}} \frac{d\vec{v}_{\text{CM}}}{dt}$$

Does the center of
mass **exist**?



Does the center of mass **exist**?

In this particular example, there is indeed a material point, inside Earth, that would follow the trajectory of the center of mass. However, there are other situations in which the center of mass is not instantiated by any material point.

However, within the substantivalist's perspective, space exists independent of any material content. The points associated with the center of mass trajectory are like any other points, therefore they do exist.

Particles to Gases

From 10^{24} degrees of freedom to three variables
(P, V, T) satisfying a different equation:

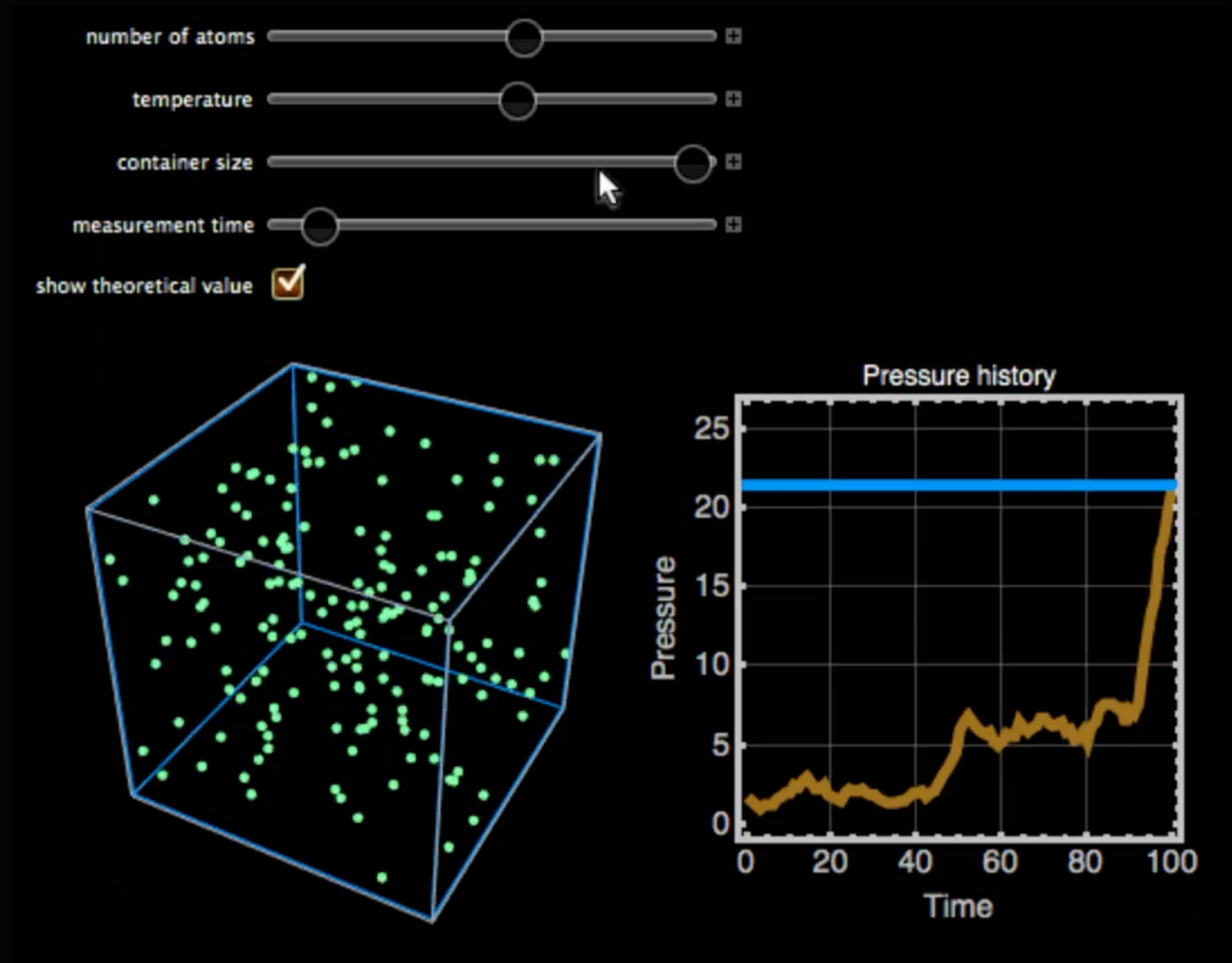
10^{24} of $(\vec{x}, \vec{p})$'s →

$$T = \frac{m\bar{v}^2}{3k_B}$$

$$P = \frac{Nm\bar{v}^2}{3V}$$

$\vec{F}(\vec{x}_I) = m_I \frac{d\vec{v}_I}{dt}$ → (Equilibrium*)

$$PV = k_B NT$$



Emergence - Level 1

Stage Space

Degrees of
Freedom

Observables

Dynamical
Equations

•
•

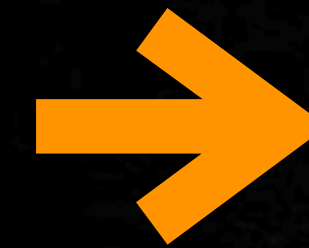
$\mathcal{M}$

10^{24} of $(\vec{x}, \vec{p})$'s

$f_a(\vec{x}_I, \vec{v}_I)$

$$\vec{F}(\vec{x}_I) = m_I \frac{d\vec{v}_I}{dt}$$

(Equilibrium*)



$\mathcal{M}$

(T, V, P)

$F_a(T, V, P)$

$$PV = k_B NT$$

(*Boltzmann Equation for out-of-equilibrium systems derived in 1872)

Does temperature
exist?

Does temperature exist?

The temperature is actually a field - it permeates space. In equilibrium, the temperature is constant, but otherwise it varies point-wise. It's not defined by the particles, but rather by their velocities.

Regardless, it is a novel property from the perspective of the base theory, and it is reliable in the emergent theory as it helps with predictions. Thus, at the very least, an emergent quantity.

Side Quest:

It's 1872... can we go
beyond?





souri Valley, and possibly from Oregon and British Columbia, eastward, over the lakes to Canada or New England; nine passed from the south-west, north and eastward, to the Middle or Eastern States; three passed from the south-west, eastward, to the South Atlantic States, and thence north-eastward; and two passed up north-eastward some distance off the Atlantic coast. Several of these storms divided into two portions, pursuing separate routes; and, with but one or two exceptions, they all increased in severity as they advanced eastward. The rainfall returns show a general deficiency on the Pacific coast; that, however, which was reported in the States east of the Rocky Mountains in March is probably compensated by the excess during January and February. During the entire three months the temperature has been colder than usual—at least for the country east of the Rocky Mountains.

WE have received the programme of the Leeds Naturalist's Field Club for the quarter April to June, from which we see that alternately with "exhibition of specimens and conversation," which takes place once a fortnight, papers on subjects of scientific interest are to be read. Excursions also take place on an average once a fortnight, the first object of the Club being "the minute investigation of the natural history, in all its branches, of the immediate neighbourhood of Leeds, and a more general investigation of the whole of the West Riding." This Society was founded in 1870, and was reorganised on a broader basis in March 1872, and seems to be doing good work.

A CORRESPONDENT writes, asking information with reference to the etymology of the word *aphis*.

THE following additions to the Brighton Aquarium have been made during the past week:—Picked Dogfish (*Acanthias vulgaris*), Larger Spotted Dogfish (*Syngnathus stellatus*), Lesser do. (*Syngnathus caucalis*), Monkfish (*Rhina squatina*), Spotted Rays (*Raja maculata*), Sharp-nosed do. (*Raja linnaei*), Streaked Gurnards (*Trigla linnaei*), Grey Gurnards (*Trigla gurnardus*), Greater Weewees (*Trachinus draco*), Lesser do. (*Trachinus vipera*), Gemmeous Dragonets (*Callionymus lyra*), Lump Fish (*Cyclopterus lumpus*), Sea Snail (*Liparis vulgaris*), Varrell's Blenny (*Blennius acanthurus*), Sand Smelt (*Atherina presbyter*), Turbot (*Rhinus maximus*), Brill (*Rhinus laticus*), Sail Fluke (*Rhinus punctatus*), Plaice (*Pleuronectes platessa*), Flounders (*Pleuronectes fenus*), Soles (*Solea vulgaris*), Minnows (*Leuciscus phoxinus*), Tench (*Tinca vulgaris*), Masked Crab (*Corystes cassidatus*), Tube Worms (*Serpula contortuplicata*), Sea Mice (*Aphrodite aculeata*), Sun Starfish (*Solaster pappus*), Mediterranean Corals (*Balanophyllia verrucosa*), Golden Cup Coral (*Balanophyllia regia*), Devonshire Cup Coral (*Caryophyllia smithii*), Sea-fingers (*Alicynium digitatum*), Sea-anemones (various).

THE additions to the Zoological Society's Gardens during the past week include an Indian leopard (*Felis pardus*), two Indian jackals (*Canis aureus*), presented by Capt. Henry; a Malabar Squirrel (*Sciurus maximus*), presented by Mr. White-side; three Egyptian cats *Felis chaus* (?) from Cashmere, presented by Capt. J. J. Bradshaw; two Egyptian geese (*Chenalex aegyptiaca*), presented by Mr. H. W. Thornton; a hawk-finch (*Coccothraustes vulgaris*), from the British Isles, presented by the Viscountess Downe; four European Terrapins (*Emys insularis*) and a green lizard (*Lacerta viridis*, var. *chironomus*), presented by Lord A. Russell; two black-handed spider monkeys (*Ateles leucostictus*); a white-throated Capuchin (*Cebus hypoleucis*); a blue-fronted Amazon (*Olbrysotis cristata*); a yellow-fronted Amazon (*C. ochrocephala*), and an orange-winged Amazon (*C. amazonicus*), from Cartagena; a crested agouti (*Dasyprocta cristata*) from Colon; an alligator, and a red and yellow macaw (*Aras chloroptera*), from Baranquilla; a golden eagle (*Aquila chrysaetos*), purchased; a bladder-nosed seal (*Cystophora cristata*), from the North Atlantic, deposited.

NATURE

ON THE HYPOTHESES WHICH LIE AT THE BASES OF GEOMETRY*

III.—Application to Space.

§ 1.—By means of these inquiries into the determination of the measure relations of an n -fold extent the conditions may be declared which are necessary and sufficient to determine the metric properties of space, if we assume the independence of line-length from position and expressibility of the line-element as the square root of a quadric differential, that is to say, flatness in the smallest parts.

First, they may be expressed thus: that the curvature at each point is zero in three surface-directions; and thence the metric properties of space are determined if the sum of the angles of a triangle is always equal to two right angles.

Secondly, if we assume with Euclid not merely an existence of lines independent of position, but of bodies also, it follows that the curvature is everywhere constant; and then the sum of the angles is determined in all triangles when it is known in one.

Thirdly, one might, instead of taking the length of lines to be independent of position and direction, assume also an independence of their length and direction from position. According to this conception changes or differences of position are complex magnitudes expressible in three independent units.

§ 2.—In the course of our previous inquiries, we first distinguished between the relations of extension or partition and the relations of measure, and found that with the same extensive properties, different measure-relations were conceivable; we then investigated the system of simple size-fixings by which the measure-relations of space are completely determined, and of which all propositions about them are a necessary consequence; it remains to discuss the question how, in what degree, and to what extent these assumptions are borne out by experience. In this respect there is a real distinction between mere extensive relations, and measure relations; in so far as in the former, where the possible cases form a discrete manifoldness, the declarations of experience are indeed not quite certain, but still not inaccurate; while in the latter, where the possible cases form a continuous manifoldness, every determination from experience remains always inaccurate; be the probability ever so great that it is nearly exact. This consideration becomes important in the extensions of these empirical determinations beyond the limits of observation to the infinitely great and infinitely small; since the latter may clearly become more inaccurate beyond the limits of observation, but not the former.

In the extension of space-construction to the infinitely great, we must distinguish between *unboundedness* and *infinite extent*, the former belongs to the extent relations, the latter to the measure-relations. That space is an unbounded three-fold manifoldness, is an assumption which is developed by every conception of the outer world; according to which every instant the region of real perception is completed and the possible positions of a sought object are constructed, and which by these applications is ever confirming itself. The unboundedness of space possesses in this way a greater empirical certainty than any external experience. But its infinite extent by no means follows from this; on the other hand if we assume independence of bodies from position, and therefore ascribe to space constant curvature, it must necessarily be finite, provided this curvature has ever so small a positive value. If we prolong all the geodesics starting in a given surface-element, we should obtain an unbounded surface of constant curvature, i.e., a surface which in a flat manifoldness of three dimensions would take the form of a sphere, and consequently be finite.

§ 3. The questions about the infinitely great are for the interpretation of nature useless questions. But this is not the case with the questions about the infinitely small. It is upon the exactness with which we follow phenomena into the infinitely small that our knowledge of their causal relations essentially depends. The progress of recent centuries in the knowledge of mechanics depends almost entirely on the exactness of the construction which has become possible through the invention of the infinitesimal calculus, and through the simple principles discovered by Archimedes, Galileo, and Newton, and used by modern physics. But in the natural sciences which are still in want of simple principles for such constructions, we seek to discover the causal relations by following the phenomena into great minuteness, so far as the microscope permits. Questions

(Continued from page 17.)

ON THE HYPOTHESES WHICH LIE AT THE BASES OF GEOMETRY*

about the measure-relations of space in the infinitely small are not therefore superfluous questions.

If we suppose that bodies exist independently of position, the curvature is everywhere constant, and it then results from astronomical measurements that it cannot be different from zero; or at any rate its reciprocal must be an area in comparison with which the range of our telescopes may be neglected. But if this independence of bodies from position does not exist, we cannot draw conclusions from metric relations of the great, to those of the infinitely small; in that case the curvature at each point may have an arbitrary value in three directions, provided that the total curvature of every measurable portion of space does not differ sensibly from zero. Still more complicated relations may exist if we no longer suppose the linear element expressible as the square root of a quadric differential. Now it seems that the empirical notions on which the metric determinations of space are founded, the notion of a solid body and of a ray of light, cease to be valid for the infinitely small. We are therefore quite at liberty to suppose that the metric relations of space in the infinitely small do not conform to the hypotheses of geometry; and we ought in fact to suppose it, if we can thereby obtain a simpler explanation of phenomena.

The question of the validity of the hypotheses of geometry in the infinitely small is bound up with the question of the ground of the metric relations of space. In this last question, which we may still regard as belonging to the doctrine of space, is found the application of the remark made above; that in a discrete manifoldness, the ground of its metric relations is given in the notion of it, while in a continuous manifoldness, this ground must come from outside. Either therefore the reality which underlies space must form a discrete manifoldness, or we must seek the ground of its metric relations outside it, in binding forces which act upon it.

The answer to these questions can only be got by starting from the conception of phenomena which has hitherto been justified by experience, and which Newton assumed as a foundation, and by making in this conception the successive changes required by facts which it cannot explain. Researches starting from general notions, like the investigation we have just made, can only be useful in preventing this work from being hampered by too narrow views, and progress in knowledge of the interdependence of things from being checked by traditional prejudices.

This leads us into the domain of another science, of physics, into which the object of this work does not allow us to go today.

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THE DEVELOPMENT THEORY IN GERMANY*

III.

Chorology: or, the Geographical Distribution of Living Beings

THE importance of the theory of Evolution does not consist in its accounting for this or that particular fact, but in its explaining all biological facts collectively. It is found to be confirmed in every detail by the mode of distribution of the various organisms on the surface of the earth. This distribution had already been studied by Alexander von Humboldt and Fr. Schouw for plants, by Berghaus and Schmarda for animals. But previous to Darwin and Wallace, this study had produced only a collection of unsystematised facts; Haeckel has attempted to create out of it a special science under the name of *Chorology*.

With the exception of the monocellular protozoa, which, on account of their simplicity, have been able to appear at the same time or at several times in different places; with the exception also of species which owe their origin to a hybrid or bastard generation, and which it has been possible to reproduce in different circumstances wherever the parent species have previously spread, it must be admitted that each of the other species has only been originated a single time and in a single place. But, once produced, they must, as a consequence of the struggle for existence, and in virtue of the laws of population, or rather of excess of population, tend to spread to the widest possible extent. Animals and plants migrate as well as man, both actively and passively.

In the case of animals, which have, more than plants, freedom of movement, active migration plays the principal part. The more easy locomotion is in the case of any species, the more rapidly is the species bound to spread. This is why birds and insects, furnished with wings, although referable to a less number of orders or natural groups than other animals, yet present a very great diversity of species slightly distinguishable from one another; this is to be ascribed to the fact that the facility with which they can move from place to place has subjected them to the modifying influences of the most varied localities. After birds and insects the swiftest runners among the denizens of the land, the best swimmers among the inhabitants of the water have been subject to the widest extension. With regard to animals which are fixed or immovable while being developed, corals, tubicolans, tunicals, crinoids, &c., they usually enjoy during their youth so much of the power of movement as admits of their displacement. A great number of floating plants are also transported to great distances by water.

But the spread of a large number of plants and of certain animals can be explained only by a passive migration. The wind sweeps to great distances, sometimes over seas, eggs of small animals, seeds, and sometimes even minute organisms; this explains the well-known phenomena of showers of frogs. These eggs, these seeds, these small organisms, sometimes fall into the water, which transports them to still greater distances. Trunks of trees, which traverse the ocean under the direction of the currents, and those which the tempest hurls from the mountain tops, can carry with them, hidden in their interstices, in the moss or the parasitical plants with which they are covered, in the earth which adheres to their roots, innumerable germs to be developed in new regions. The icebergs of the polar sea have landed foxes and bears even on the shores of Iceland and Britain. Birds, insects, mammals which are removed, carry with them thousands of parasites, microscopic beings, eggs or germs. Man himself carries them about more abundantly still along with the varied materials he employs for his works and his industry.

The fact of the distribution of certain species which cannot be explained by migration, either active or passive, may be accounted for by geological facts. In consequence of the im-

* Continued from vol. vii. p. 434.

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Now it seems that the empirical notions on which the metrical determinations of space are founded, the notion of a solid body and of a ray of light, cease to be valid for the infinitely small. We are therefore quite at liberty to suppose that the metric relations of space in the infinitely small do not conform to the hypotheses of geometry; and we ought in fact to suppose it, if we can thereby obtain a simpler explanation of phenomena.



souri Valley, and possibly from Oregon and British Columbia, eastward, over the lakes to Canada or New England; nine passed from the south-west, north and eastward, to the Middle or Eastern States; three passed from the south-west, eastward, to the South Atlantic States, and thence north-eastward; and two passed up north-eastward some distance off the Atlantic coast. Several of these storms divided into two portions, pursuing separate routes; and, with but one or two exceptions, they all increased in severity as they advanced eastward. The rainfall returns show a general deficiency on the Pacific coast; that, however, which was reported in the States east of the Rocky Mountains in March is probably compensated by the excess during January and February. During the entire three months the temperature has been colder than usual—at least for the country east of the Rocky Mountains.

WE have received the programme of the Leeds Naturalist's Field Club for the quarter April to June, from which we see that alternately with "exhibition of specimens and conversation," which takes place once a fortnight, papers on subjects of scientific interest are to be read. Excursions also take place on an average once a fortnight, the first object of the Club being "the minute investigation of the natural history, in all its branches, of the immediate neighbourhood of Leeds, and a more general investigation of the whole of the West Riding." This Society was founded in 1870, and was reorganised on a broader basis in March 1872, and seems to be doing good work.

A CORRESPONDENT writes, asking information with reference to the etymology of the word *aphis*.

THE following additions to the Brighton Aquarium have been made during the past week:—Picked Dogfish (*Acanthias vulgaris*), Larger Spotted Dog-fish (*Syngnium stellare*), Lesser do. (*Syngnium caucalis*), Monkfish (*Rhina squatina*), Spotted Rays (*Raja maculata*), Sharp-nosed do. (*Raja linna*), Streaked Gurnards (*Trigla linna*), Grey Gurnards (*Trigla gurnardus*), Greater Weevors (*Trachinus draco*), Lesser do. (*Trachinus vifera*), Gemmeous Dragonets (*Callionymus lyra*), Lump Fish (*Cyclopterus lumpus*), Sea Snail (*Liparis vulgaris*), Varrell's Blenny (*Blennius acanin*), Sand Smelt (*Atherina presbyter*), Turbot (*Rhombus maximus*), Brill (*Rhombus loric*), Sail Fluke (*Rhombus punctatus*), Plaice (*Pleuronectes platessa*), Flounders (*Pleuronectes fenus*), Soles (*Solea vulgaris*), Minnows (*Leuciscus phoxinus*), Tench (*Tinca vulgaris*), Masked Crab (*Corystes cassidarius*), Tube Worms (*Serpula contortuplicata*), Sea Mice (*Aphrodite aculeata*), Sun Starfish (*Solaster pappus*), Mediterranean Corals (*Balanophyllia verrucosa*), Golden Cup Coral (*Balanophyllia regia*), Devonshire Cup Coral (*Caryophyllia smithii*), Sea-fingers (*Alycinium digitatum*), Sea-anemones (various).

THE additions to the Zoological Society's Gardens during the past week include an Indian leopard (*Felis pardus*), two Indian jackals (*Canis aureus*), presented by Capt. Henry; a Malabar Squirrel (*Sciurus maximus*), presented by Mr. White-side; three Egyptian cats *Felis chaus* (?) from Cashmere, presented by Capt. J. J. Bradshaw; two Egyptian geese (*Chenalexgyptiaca*), presented by Mr. H. W. Thornton; a hawk-finch (*Coccothraustes vulgaris*), from the British Isles, presented by the Viscountess Downe; four European Terrapins (*Emys insularis*) and a green lizard (*Lacerta viridis*, var. *chironensis*), presented by Lord A. Russell; two black-handed spider monkeys (*Ateles melanochir*); a white-throated Capuchin (*Cebus hypoleucus*); a blue-fronted Amazon (*Olbrysotis estiva*); a yellow-fronted Amazon (*C. ochracephala*), and an orange-winged Amazon (*C. amazonicus*), from Cartagena; a crested agouti (*Dasyprocta cristata*) from Colon; an alligator, and a red and yellow macaw (*Aracolorata*), from Baranquilla; a golden eagle (*Aquila chrysaetus*), purchased; a bladder-nosed seal (*Cystophora cristata*), from the North Atlantic, deposited.

NATURE

ON THE HYPOTHESES WHICH LIE AT THE BASES OF GEOMETRY*

III.—Application to Space.

§ 1.—By means of these inquiries into the determination of the measure relations of an *n*-fold extent the conditions may be declared which are necessary and sufficient to determine the metric properties of space, if we assume the independence of line-length from position and expressibility of the line-element as the square root of a quadric differential, that is to say, flatness in the smallest parts.

First, they may be expressed thus: that the curvature at each point is zero in three surface-directions; and thence the metric properties of space are determined if the sum of the angles of a triangle is always equal to two right angles.

Secondly, if we assume with Euclid not merely an existence of lines independent of position, but of bodies also, it follows that the curvature is everywhere constant; and then the sum of the angles is determined in all triangles when it is known in one.

Thirdly, one might, instead of taking the length of lines to be independent of position and direction, assume also an independence of their length and direction from position. According to this conception changes or differences of position are complex magnitudes expressible in three independent units.

§ 2.—In the course of our previous inquiries, we first distinguished between the relations of extension or partition and the relations of measure, and found that with the same extensive properties, different measure-relations were conceivable; we then investigated the system of simple size-fixings by which the measure-relations of space are completely determined, and of which all propositions about them are a necessary consequence; it remains to discuss the question how, in what degree, and to what extent these assumptions are borne out by experience. In this respect there is a real distinction between mere extensive relations, and measure relations; in so far as in the former, where the possible cases form a discrete manifoldness, the declarations of experience are indeed not quite certain, but still not inaccurate; while in the latter, where the possible cases form a continuous manifoldness, every determination from experience remains always inaccurate; be the probability ever so great that it is nearly exact. This consideration becomes important in the extensions of these empirical determinations beyond the limits of observation to the infinitely great and infinitely small; since the latter may clearly become more inaccurate beyond the limits of observation, but not the former.

In the extension of space-construction to the infinitely great, we must distinguish between *unboundedness* and *infinite extent*, the former belongs to the extent relations, the latter to the measure-relations. That space is an unbounded three-fold manifoldness, is an assumption which is developed by every conception of the outer world; according to which every instant the region of real perception is completed and the possible positions of a sought object are constructed, and which by these applications is ever confirming itself. The unboundedness of space possesses in this way a greater empirical certainty than any external experience. But its infinite extent by no means follows from this; on the other hand if we assume independence of bodies from position, and therefore ascribe to space constant curvature, it must necessarily be finite, provided this curvature has ever so small a positive value. If we prolong all the geodesics starting in a given surface-element, we should obtain an unbounded surface of constant curvature, i.e., a surface which in a flat manifoldness of three dimensions would take the form of a sphere, and consequently be finite.

§ 3. The questions about the infinitely great are for the interpretation of nature useless questions. But this is not the case with the questions about the infinitely small. It is upon the exactness with which we follow phenomena into the infinitely small that our knowledge of their causal relations essentially depends. The progress of recent centuries in the knowledge of mechanics depends almost entirely on the exactness of the construction which has become possible through the invention of the infinitesimal calculus, and through the simple principles discovered by Archimedes, Galileo, and Newton, and used by modern physics. But in the natural sciences which are still in want of simple principles for such constructions, we seek to discover the causal relations by following the phenomena into great minuteness, so far as the microscope permits. Questions

(Continued from page 17.)

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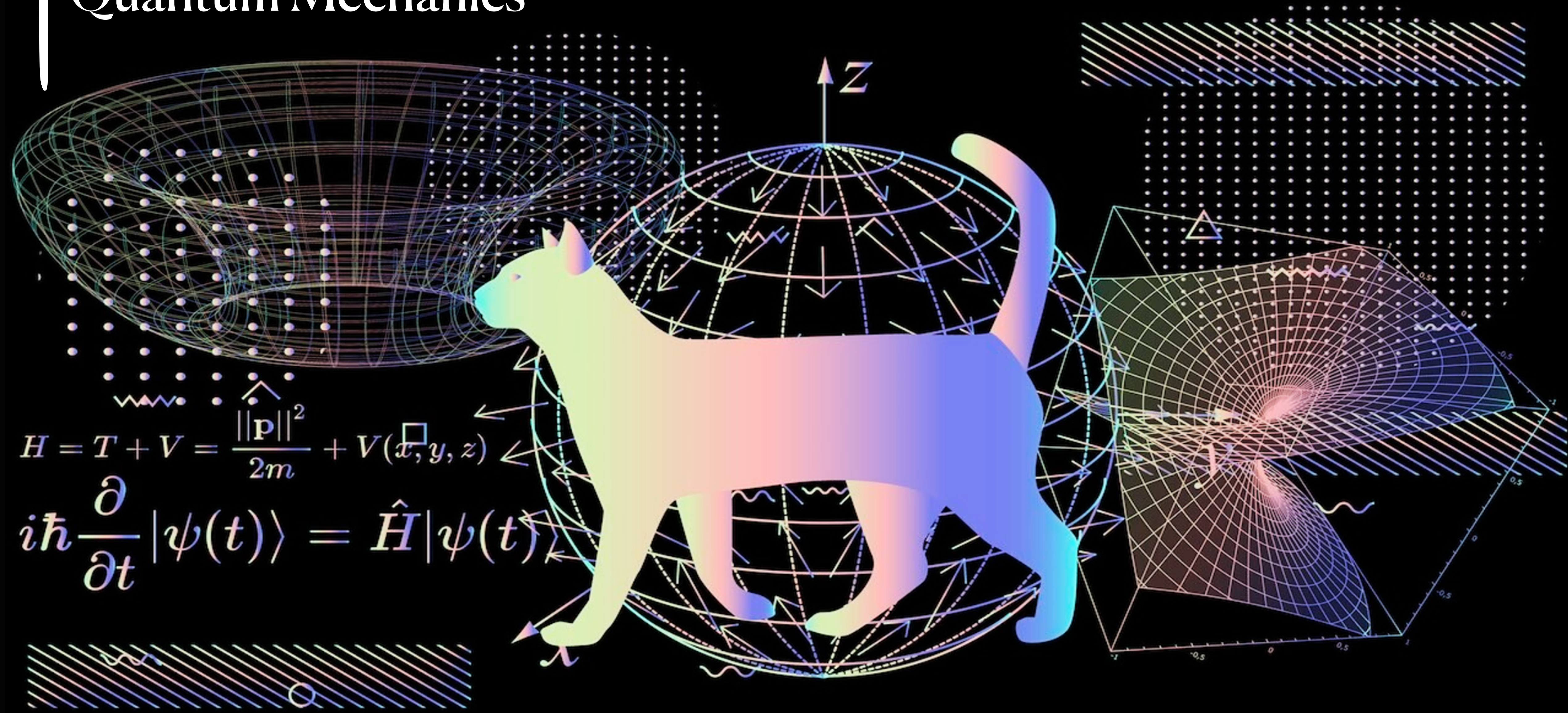
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Chapter 4:

Quantum Mechanics





(Solvay Conference, '27 - Belgium)

a) A new space: **Hilbert space, $\mathcal{H}$ - quantum space!**

b) A state: **$|\psi\rangle \in \mathcal{H}$ - the wave-function!**

c) An evolution (Schrödinger) equation*:

$$i\hbar \frac{d}{dt} |\psi\rangle = \hat{H} |\psi\rangle$$

(*Linear equation of motion: superpositions allowed!)



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?) Born rule: Prob = $|\psi_n|^2$

??) “collapse”: $|\psi\rangle \rightarrow |\psi_n\rangle$

(*Linear equation of motion: superpositions allowed!)

It's generally believed that the world is fundamentally quantum-mechanical. After all, it rules the small-world, and the big-world is made of small things, isn't it?

But quantum-mechanics is very different than classical mechanics. So, it seems that this time around it is **classical mechanics** which is the theory that is **emergent**!

Emergence - Level 2

Stage Space

Degrees of
Freedom

Observables

Dynamical
Equations

⋮

$\mathcal{H}$

Q-states $|\psi\rangle$

$$\mathcal{O}_A^\dagger = \mathcal{O}_A$$

$$i\hbar \frac{d}{dt} |\psi\rangle = \hat{H} |\psi\rangle$$

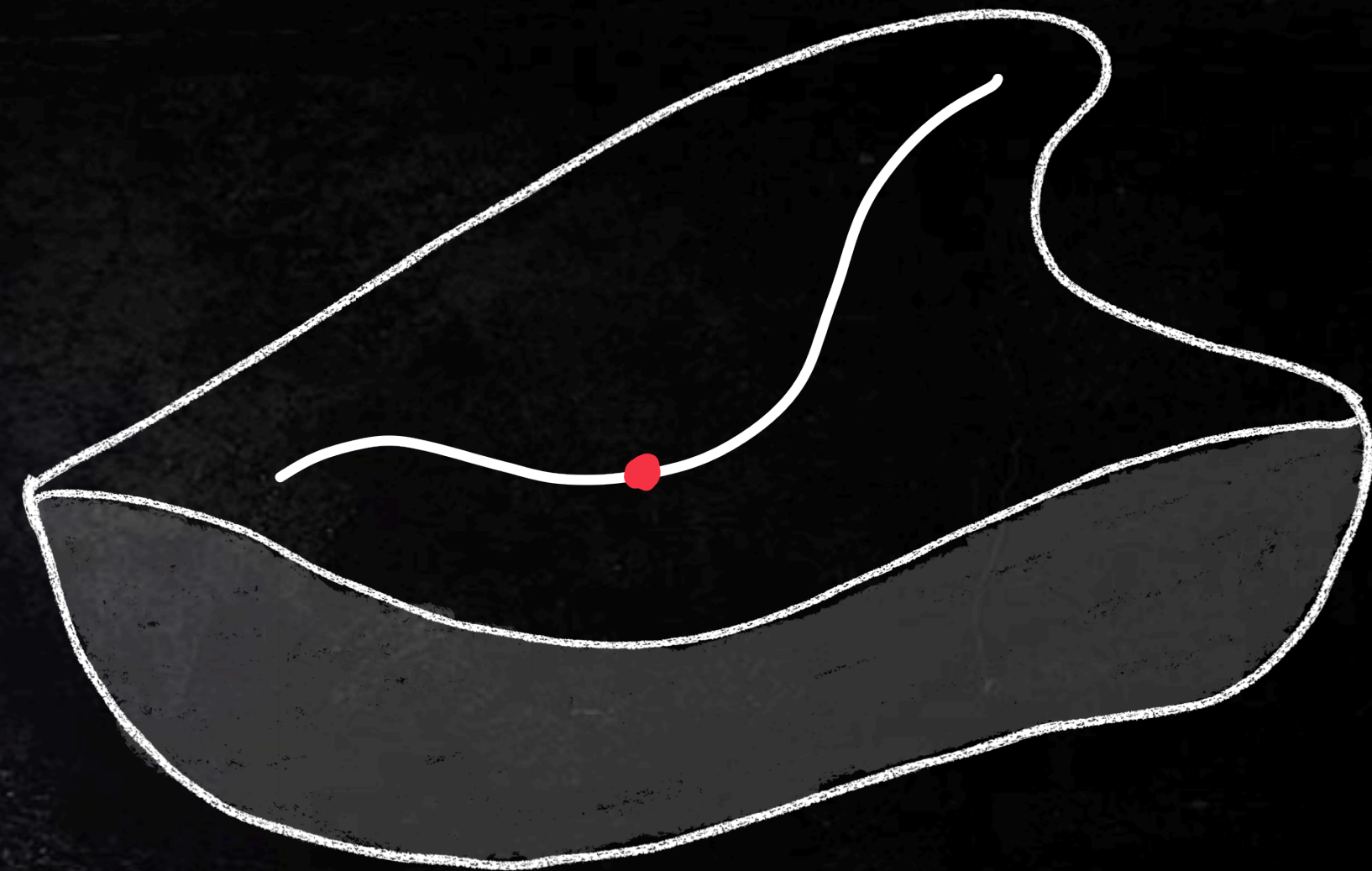


$\mathcal{M}$

$(\vec{x}_I, \vec{v}_I)$

$f_a(\vec{x}_I, \vec{v}_I)$

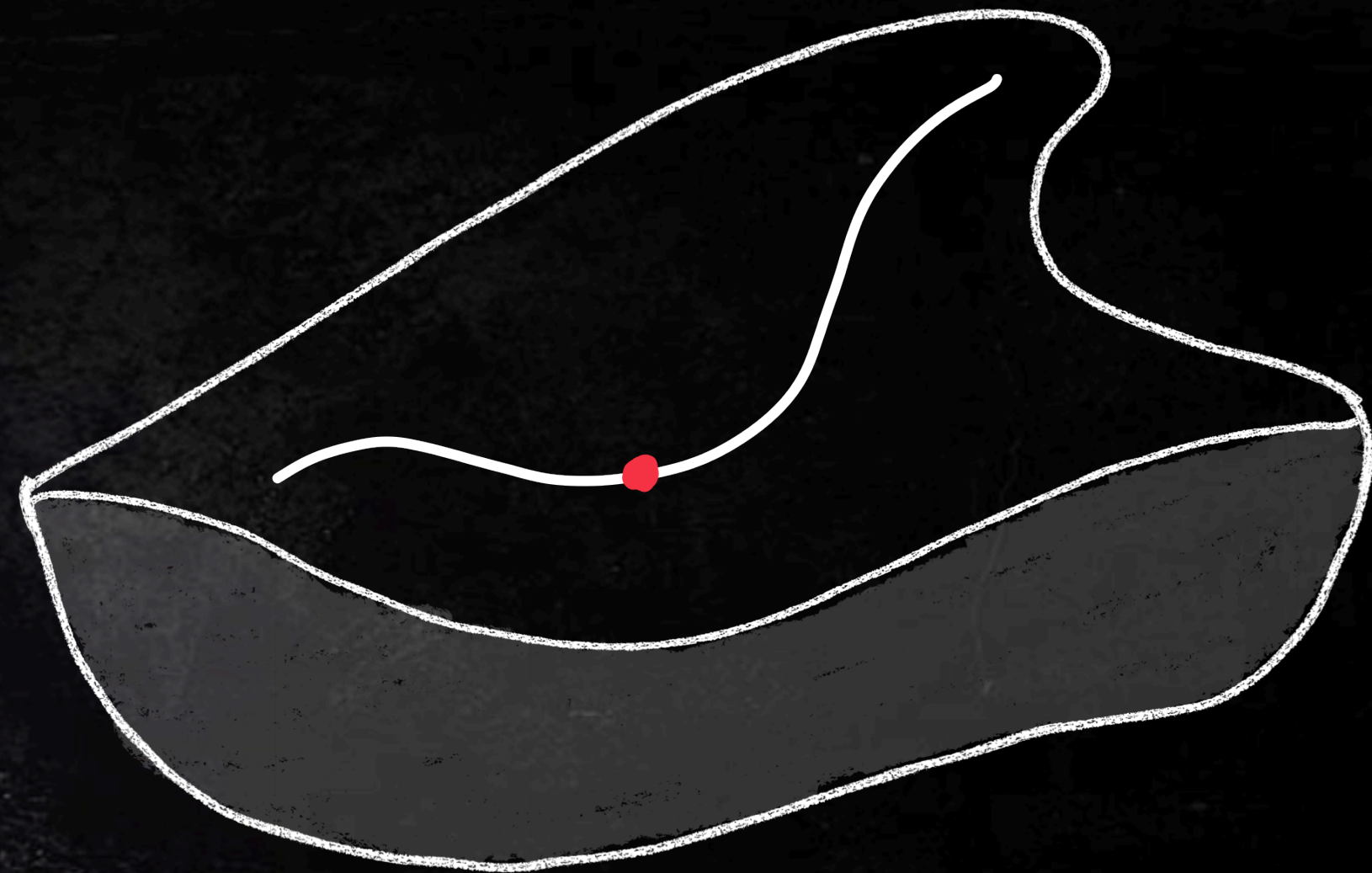
$$\vec{F}(\vec{x}_I) = m_I \frac{d^2 \vec{x}_I}{dt^2}$$



Well, if we had doubt about temperature existing or not, perhaps now we might have doubts about the entities of classical mechanics (e.g. particles) existing.



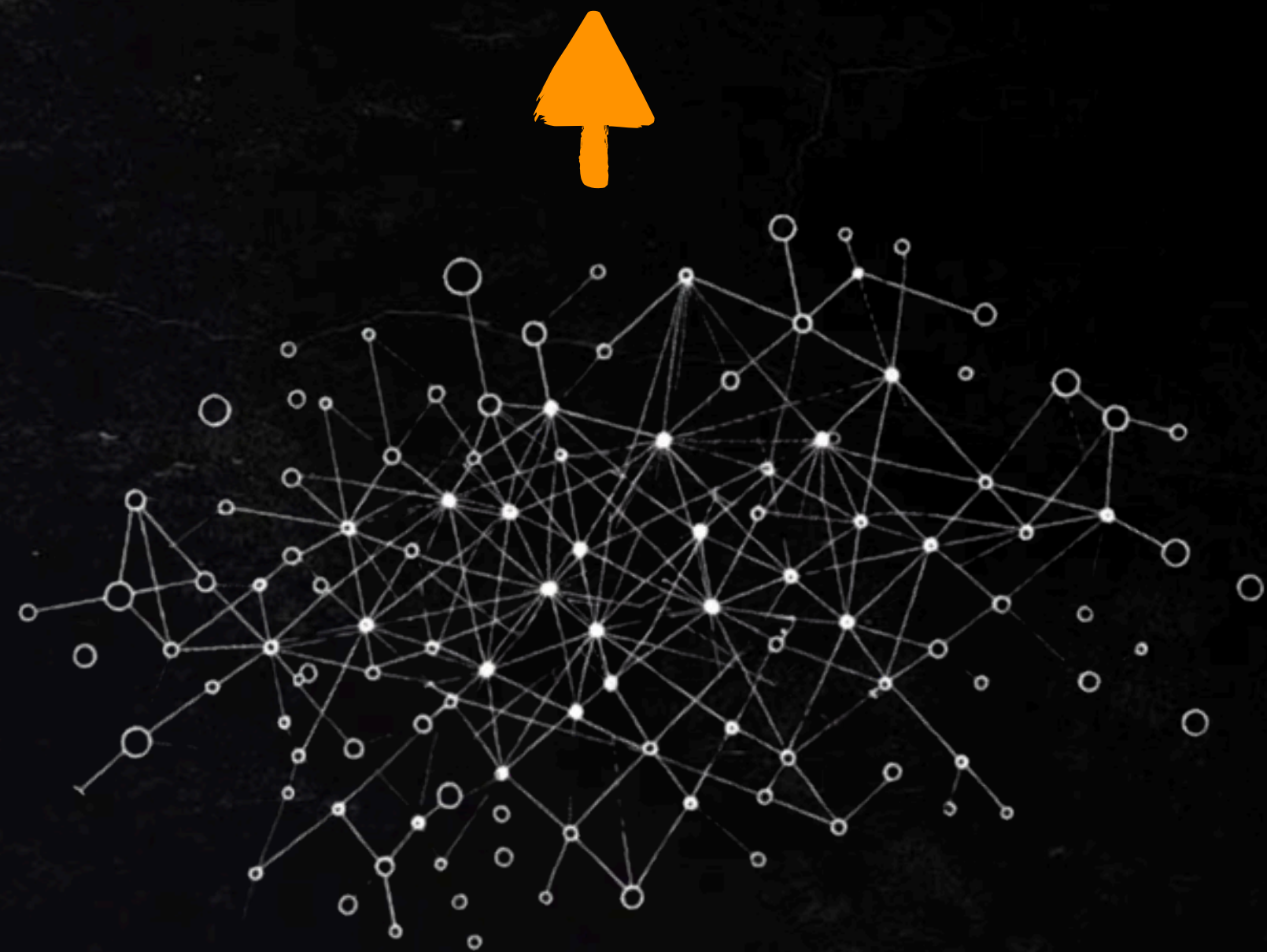
Perhaps, then we should move from a **classical ontology** (verb *to be in spacetime*) to a **quantum ontology** (verb *to be in Hilbert space*).



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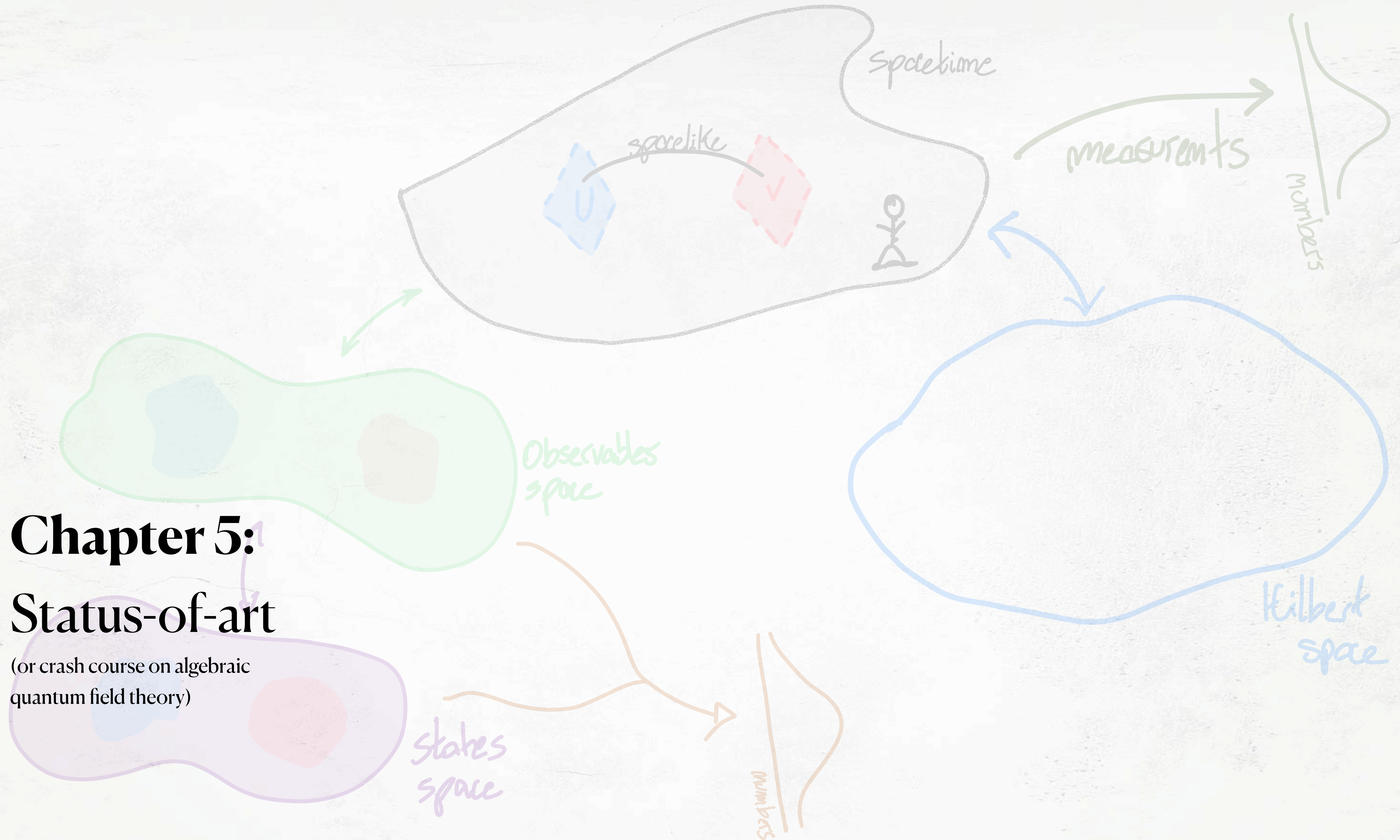
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But can we?

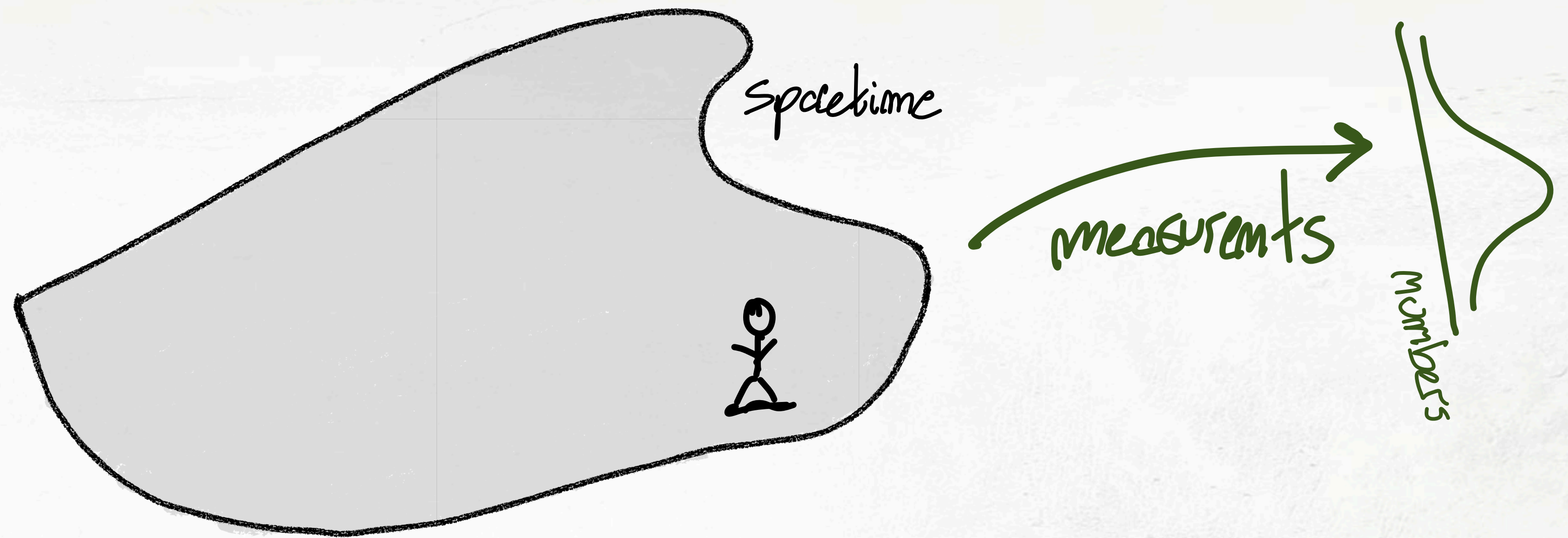


Chapter 5: Status-of-art

(or crash course on algebraic
quantum field theory)

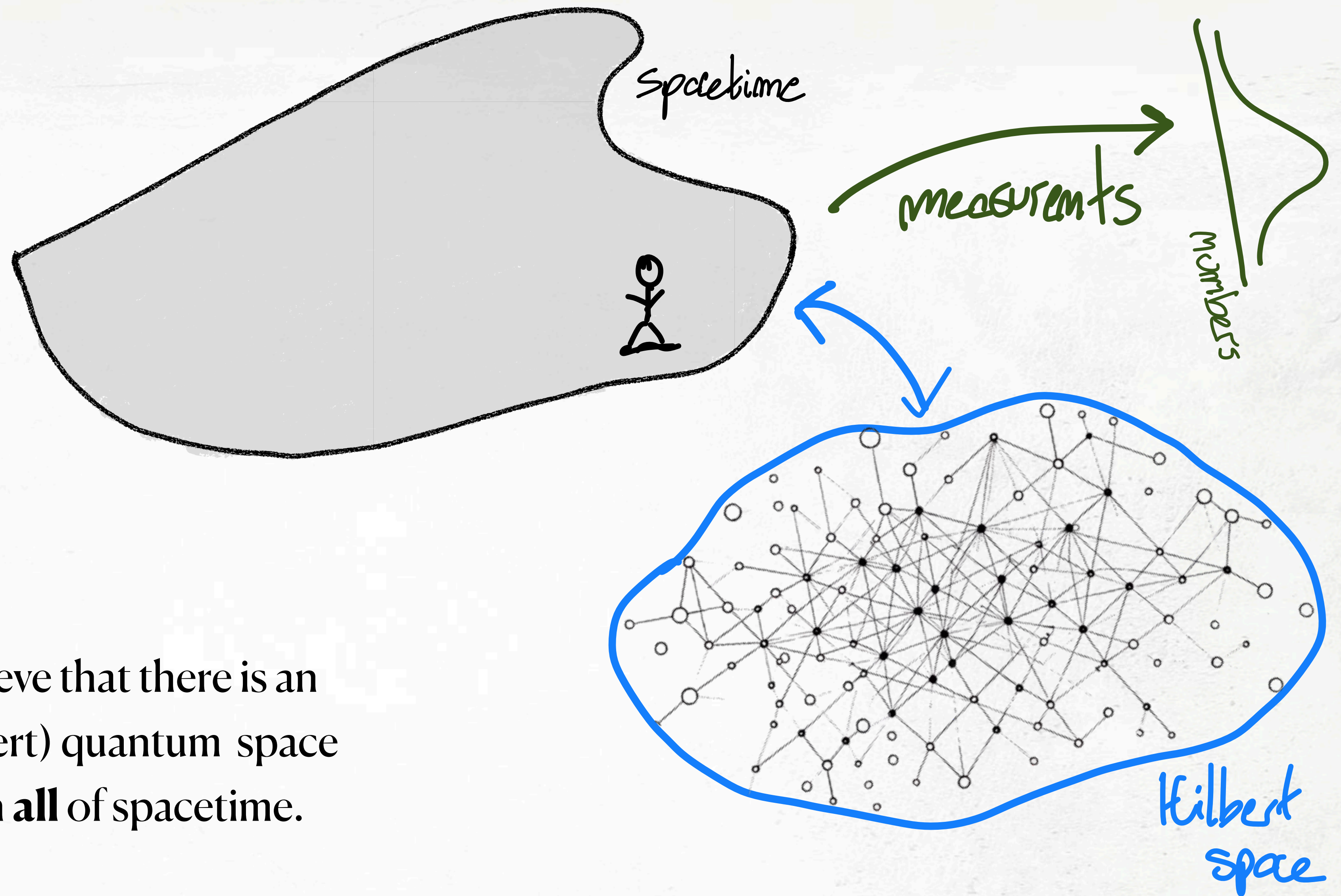


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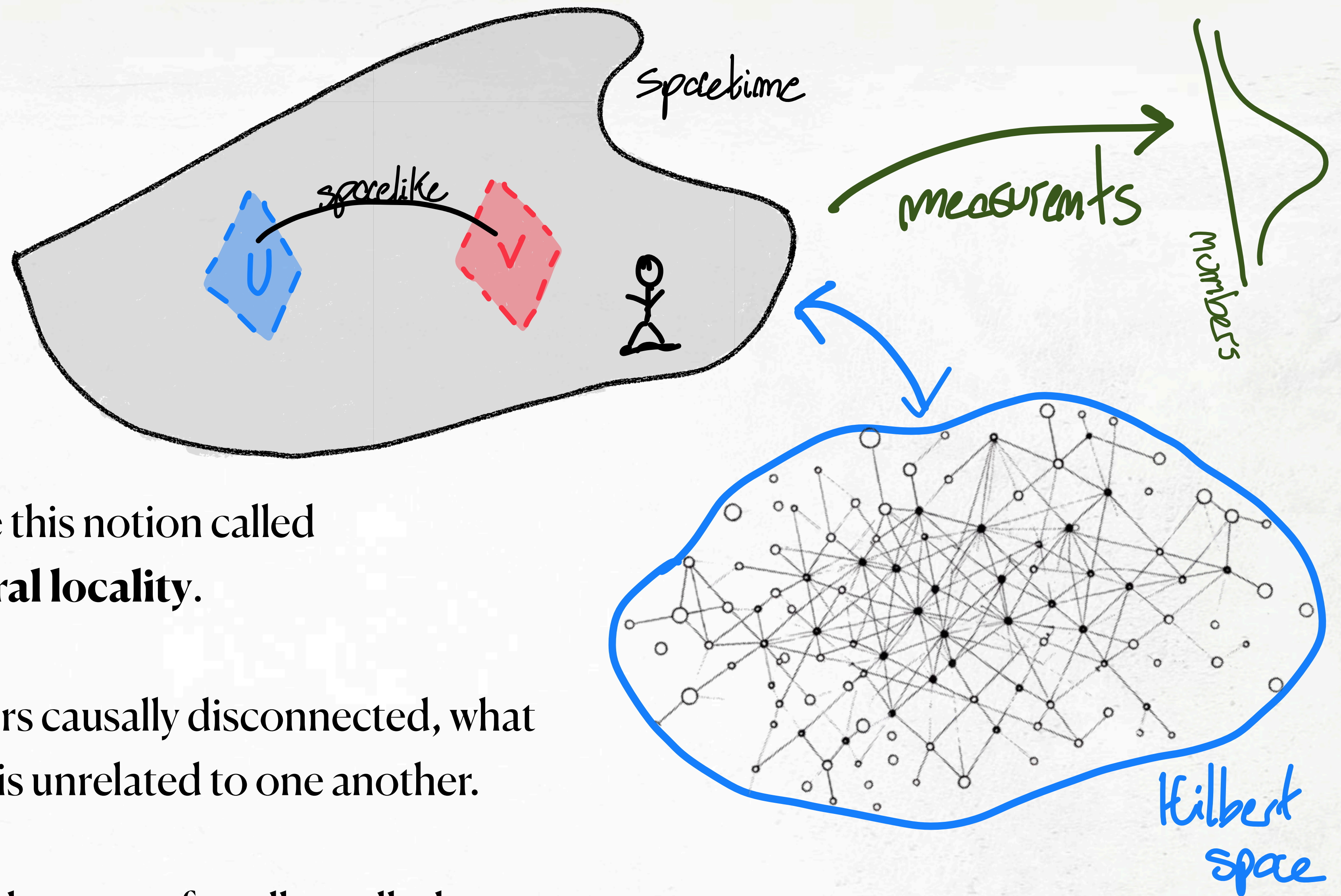
We **are in** spacetime! And we can do measurements in spacetime, which are basically counting numbers describing the state of our physical systems.

Status- of-art



But now we believe that there is an underlying (Hilbert) quantum space associated with **all** of spacetime.

Status- of-art

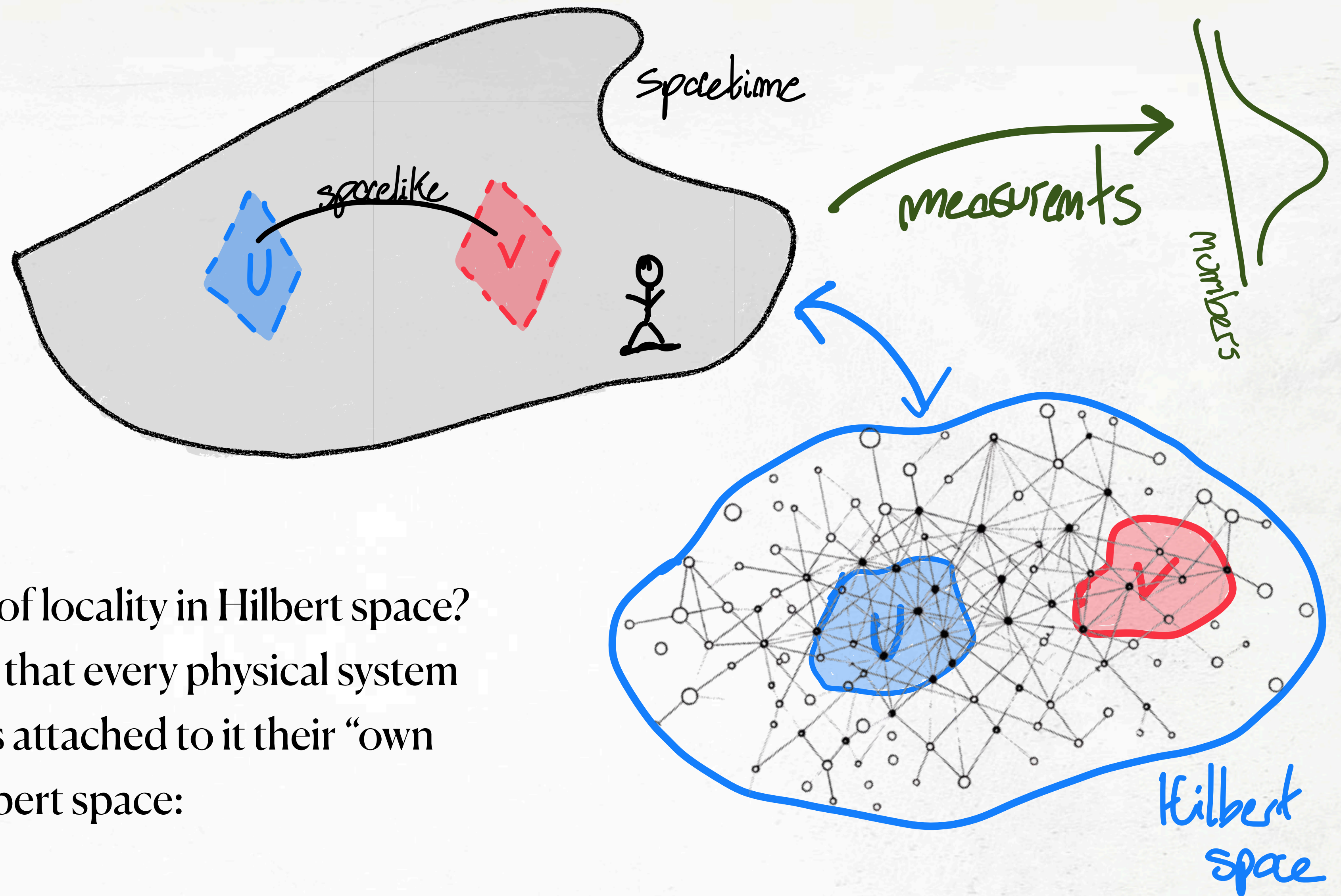


In spacetime, we have this notion called
spatiotemporal locality.

It means that for different observers causally disconnected, what happens in their surroundings is unrelated to one another.

Sounds like a good thing to have, because after all to talk about what exists we somehow need to make sense of them on their own, we need to have a criterion of distinguishability, of independence.

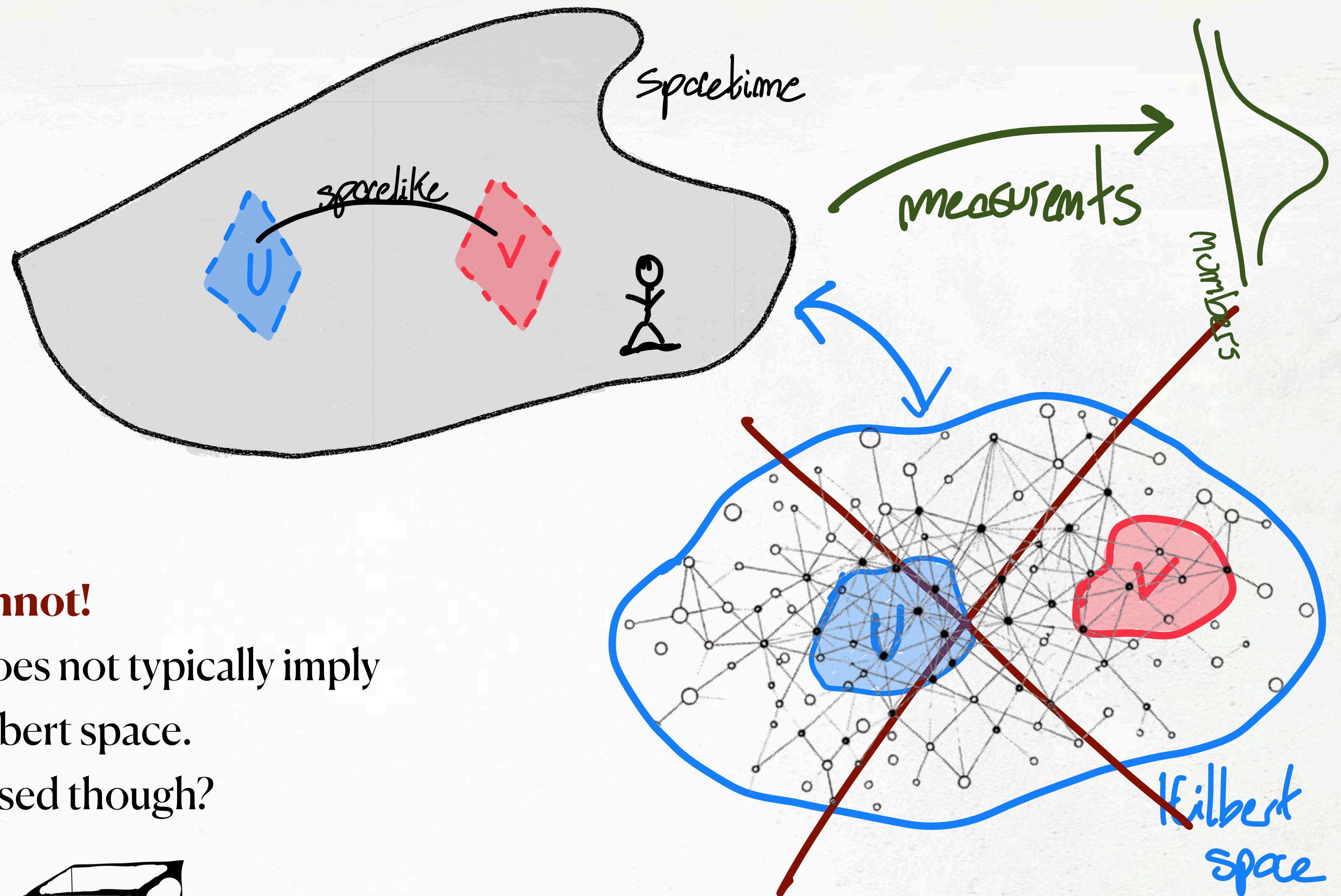
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Can we find a similar notion of locality in Hilbert space?
If so, then we could imagine that every physical system
in spacetime somehow has attached to it their "own
smaller" Hilbert space:

To be in spacetime $\leftrightarrow$ to be in Hilbert space?

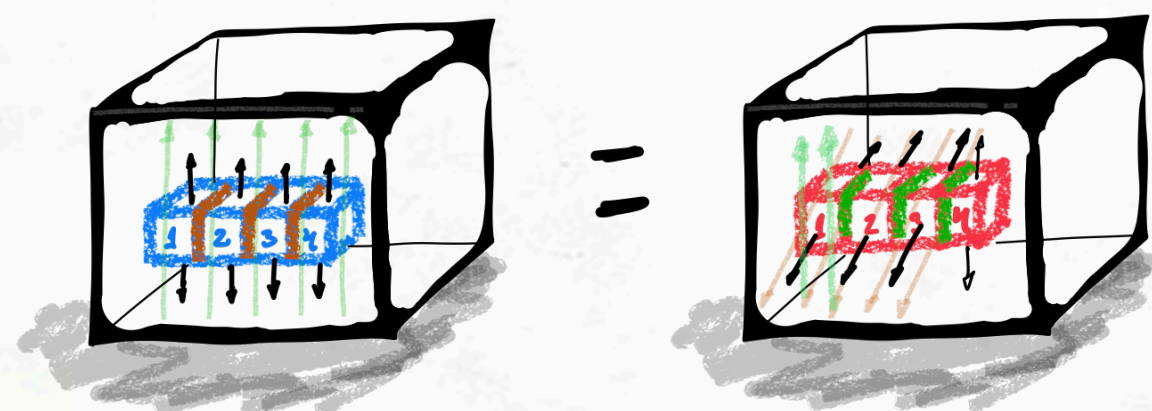
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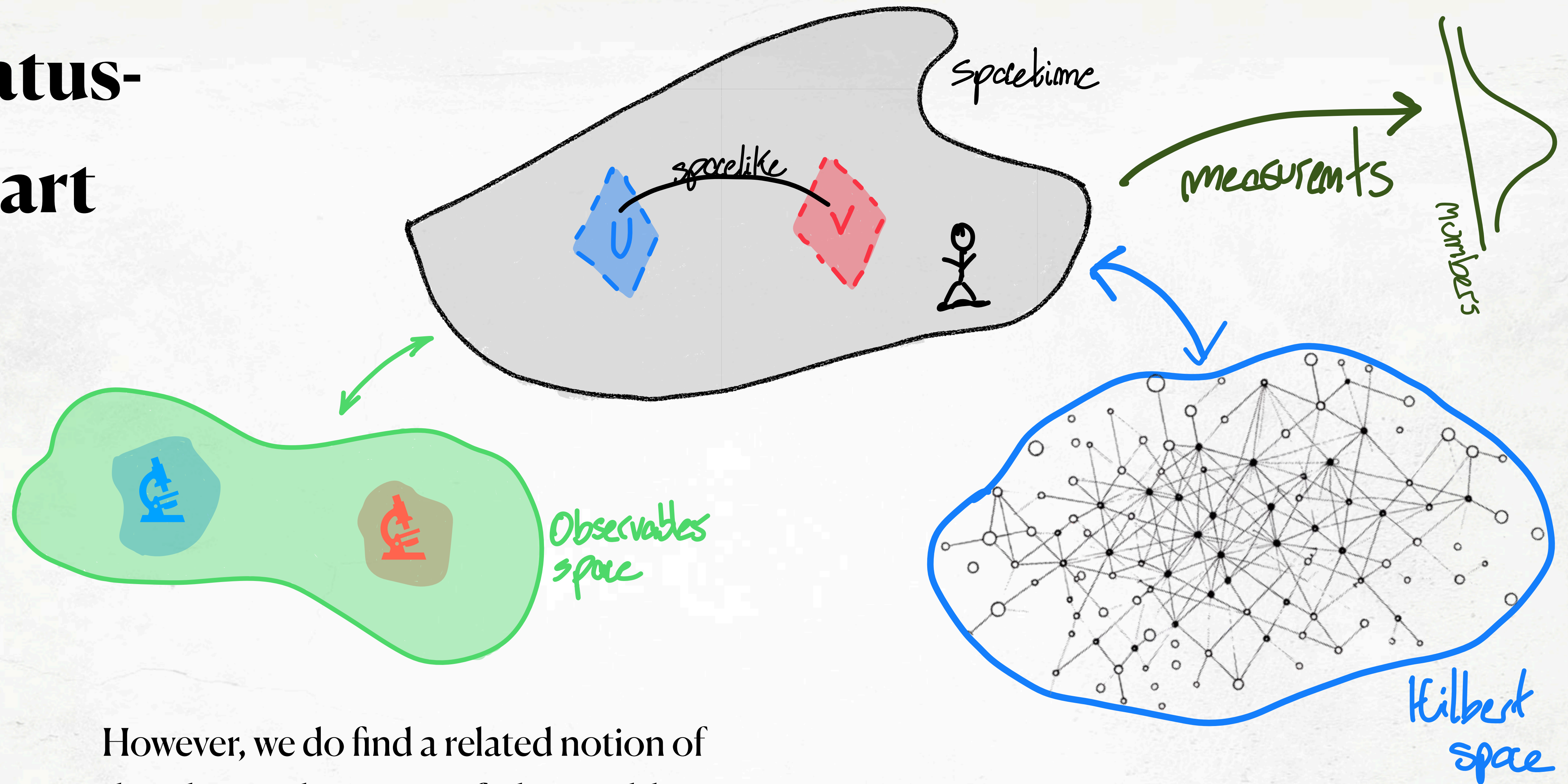
We cannot!

Locality in spacetime does not typically imply
locality in Hilbert space.

Are you surprised though?

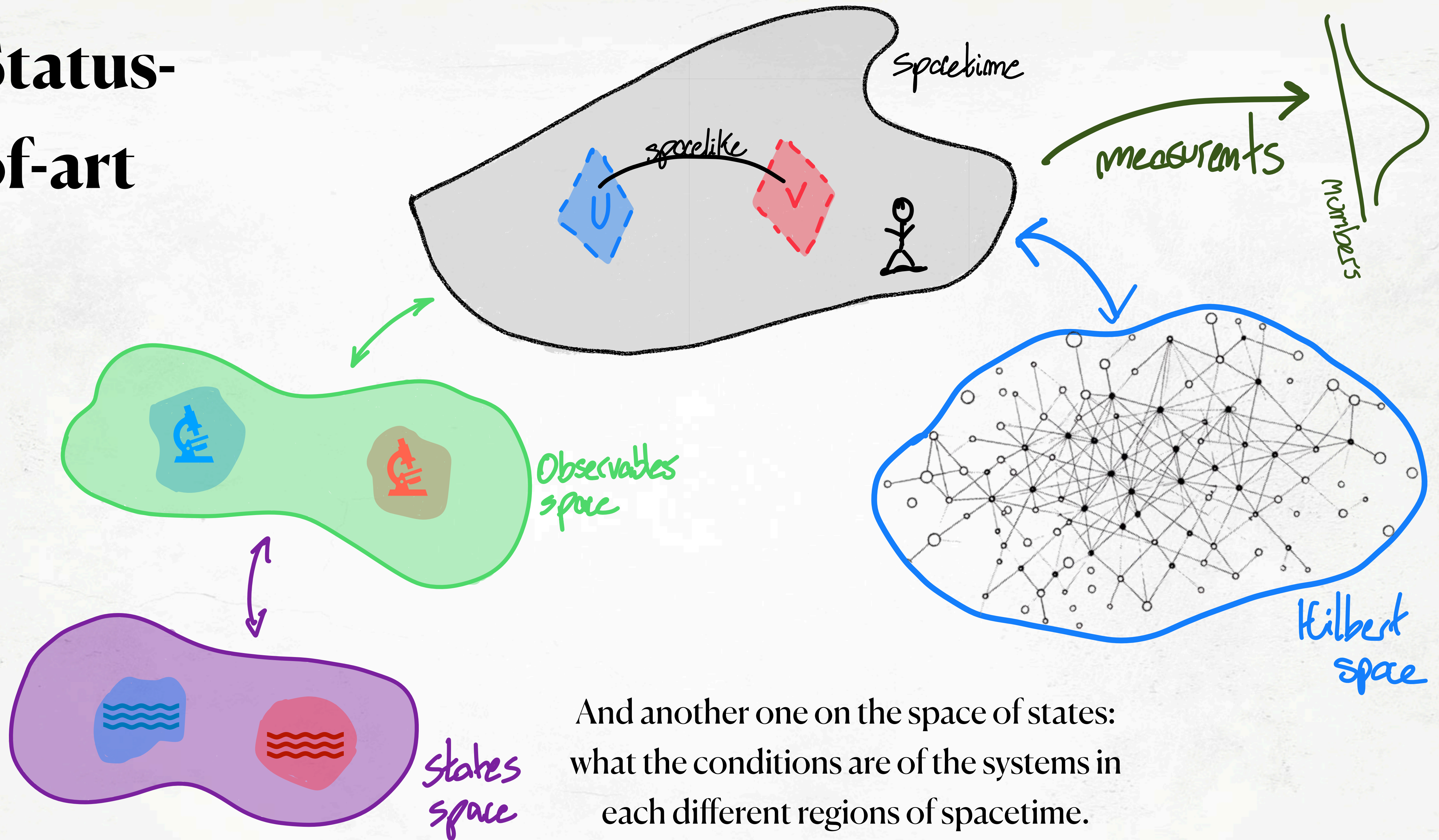


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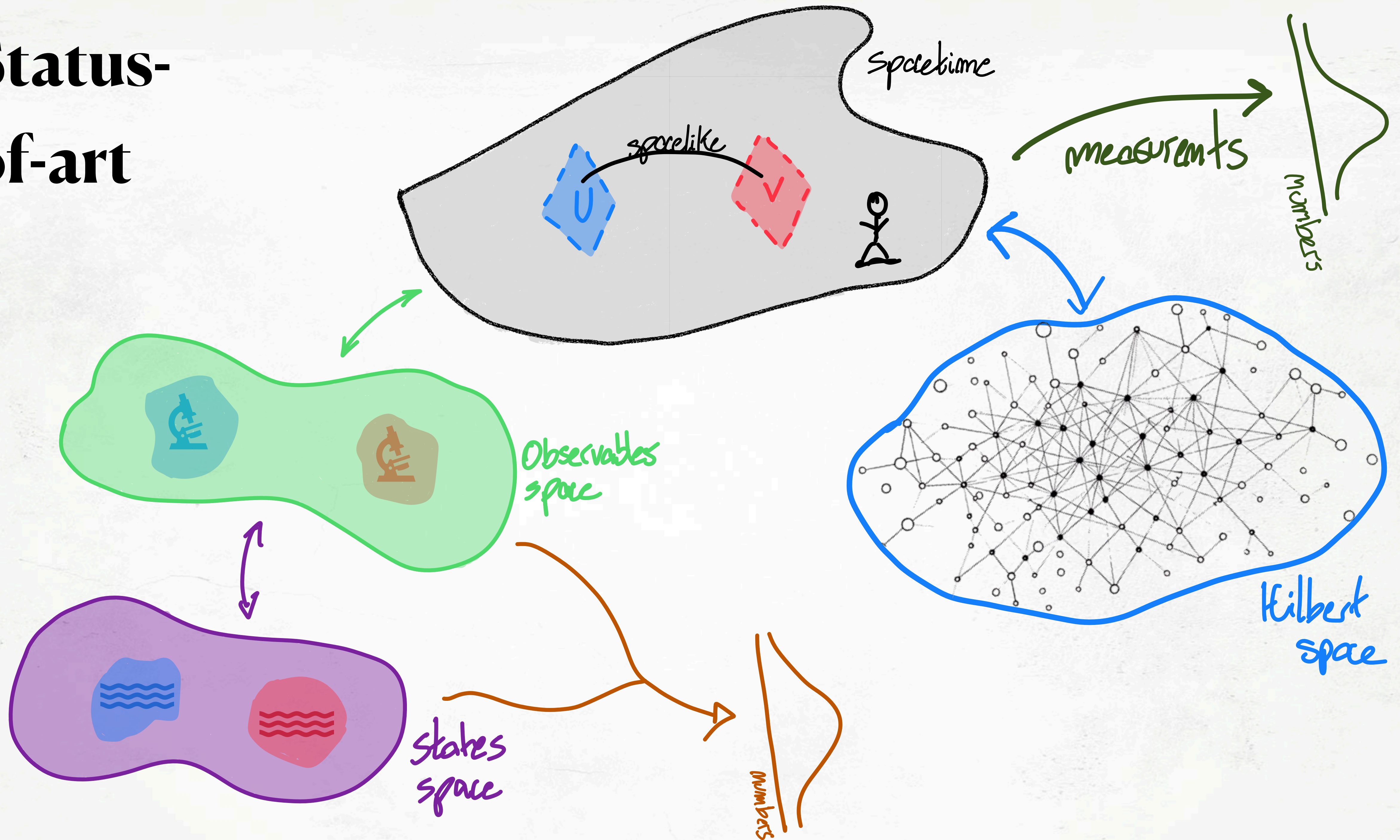


However, we do find a related notion of **locality in the space of observables** (what we can measure in each different region of spacetime).

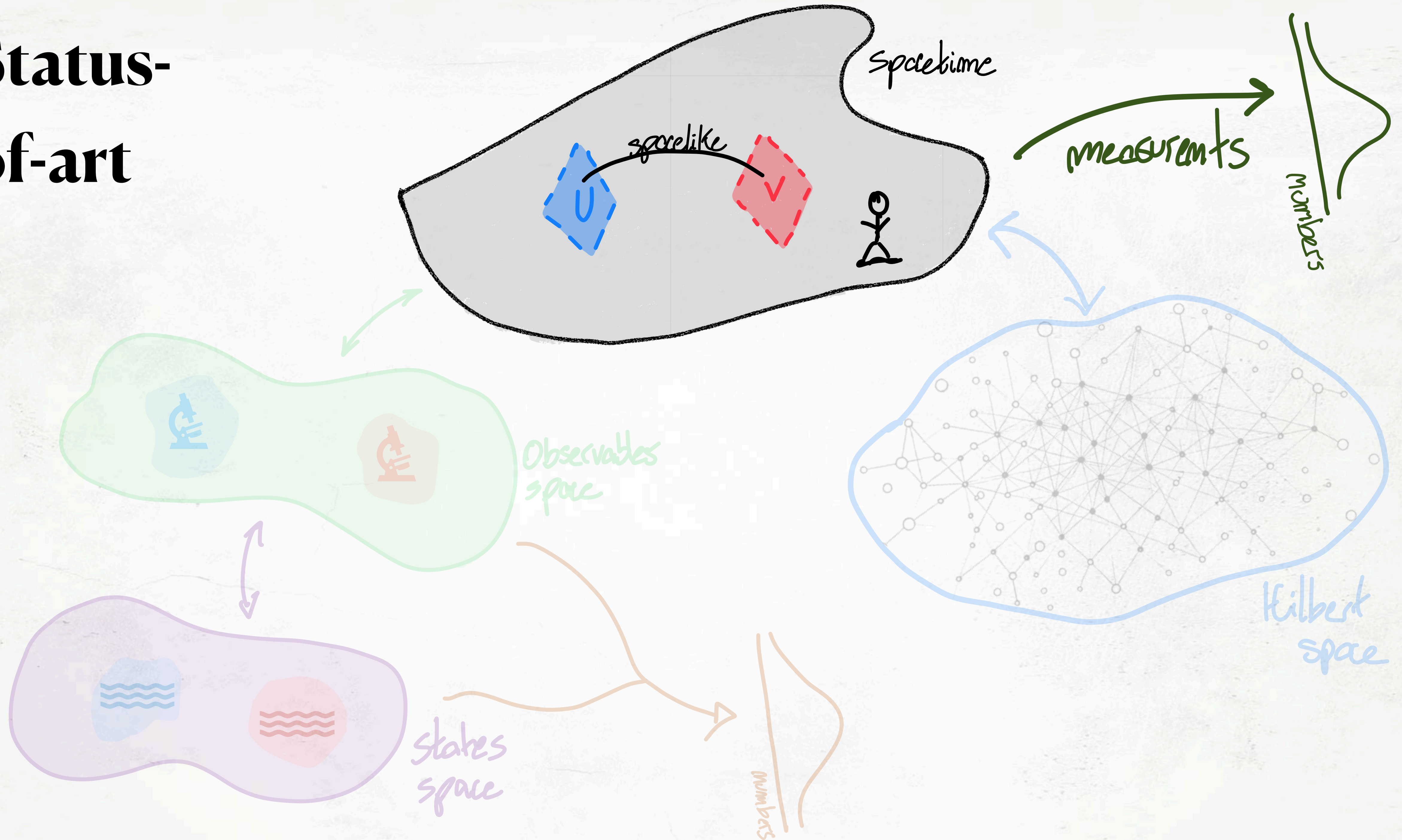
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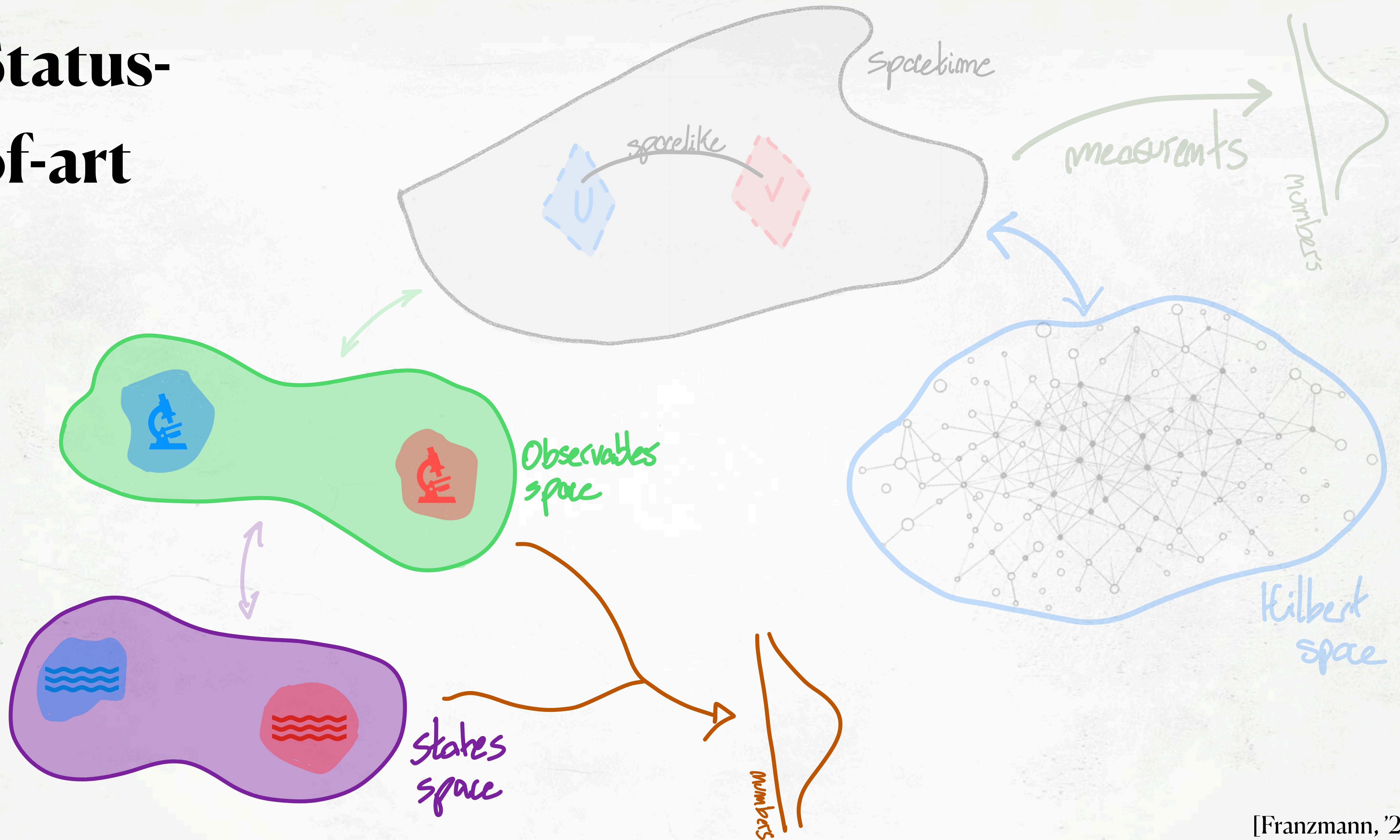


‘It is decisive to recognize that, however far the phenomena transcend the scope of classical physical explanation, **the account of all evidence must be expressed in classical terms.** The argument is simply that by the word experiment we refer to a situation where we can tell others what we have done and what we have learned and that, therefore, the account of the experimental arrangements and of the results of the observations must be expressed in unambiguous language with suitable application of the terminology of classical physics.’ (Bohr, 1949, p. 209)

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"Thus quantum mechanics occupies a very unusual place among physical theories: it contains classical mechanics as a limiting case, yet at the same time it requires this limiting case for its own formulation."
(Landau & Lifshitz, 1977, p.3)

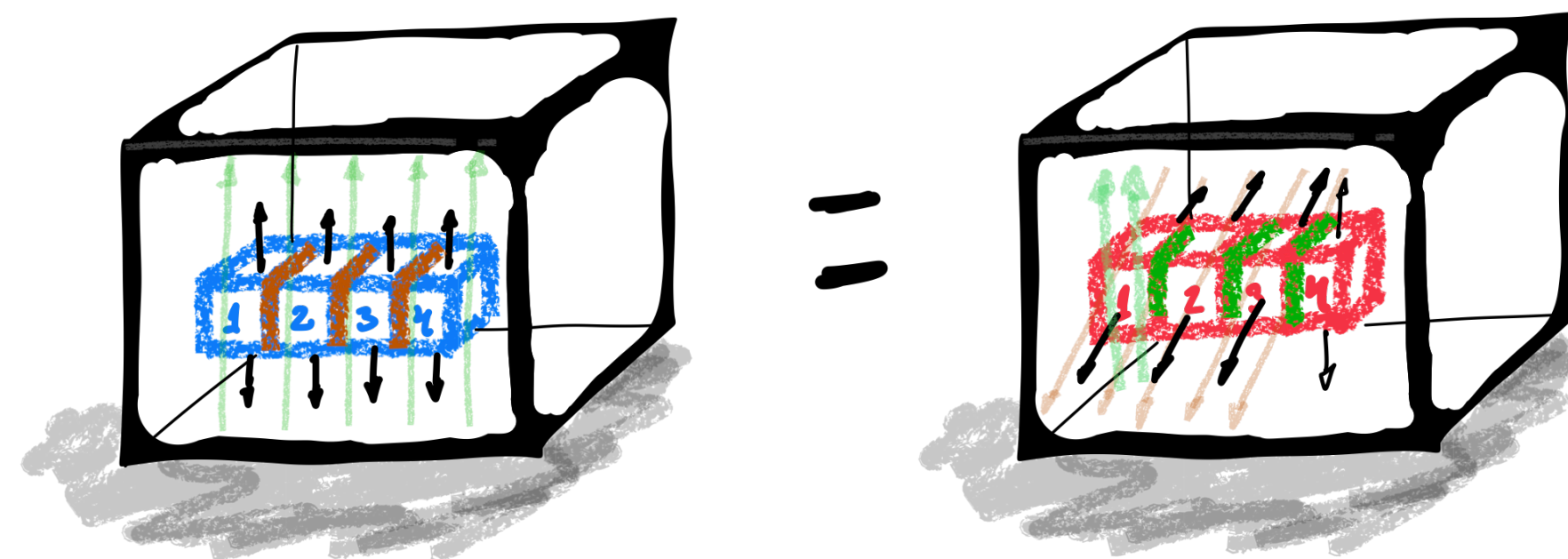
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Does this remind you of
anything?

$$H = J \sum_{i=1}^{n-1} \sigma_i^z \sigma_{i+1}^z + h \sum_{i=1}^n \sigma_i^z = J \sum_{i=1}^n \mu_i^x + h \sum_{i=1}^{n-1} \mu_i^z \mu_{i+1}^z - J \mu_n^x + h \mu_1^z$$



$$\mu_i^z = \prod_{j \leq i} \sigma_j^x, \quad \mu_i^x = \sigma_i^z \sigma_{i+1}^z, \quad \mu_n^x = \sigma_n^z$$

So, which one is it? How do we find out?

spacetime

measurements

numbers

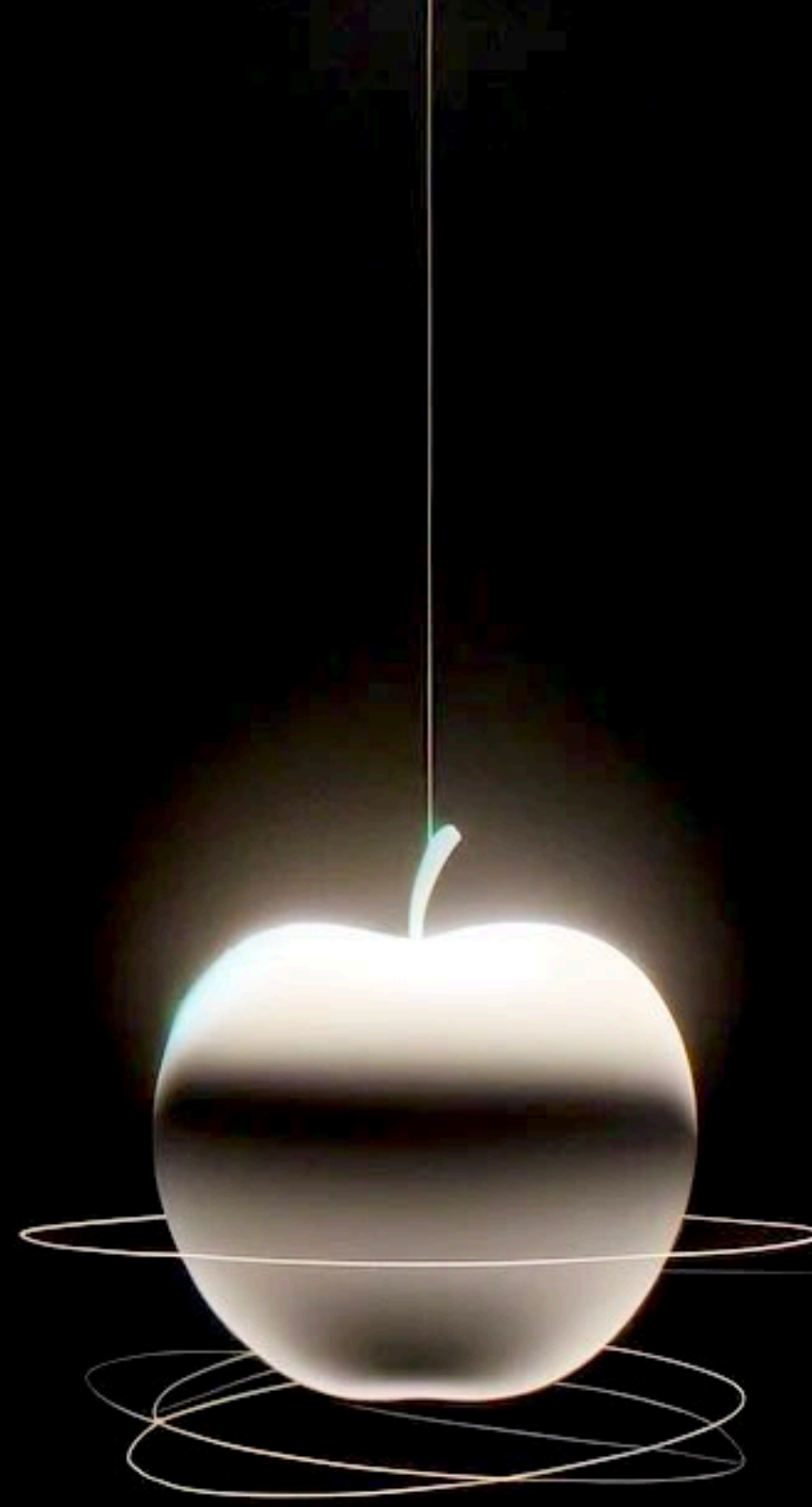
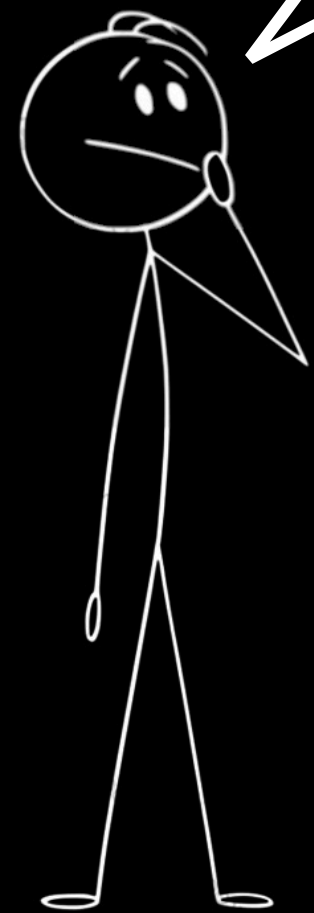
Hilbert
space

states
space

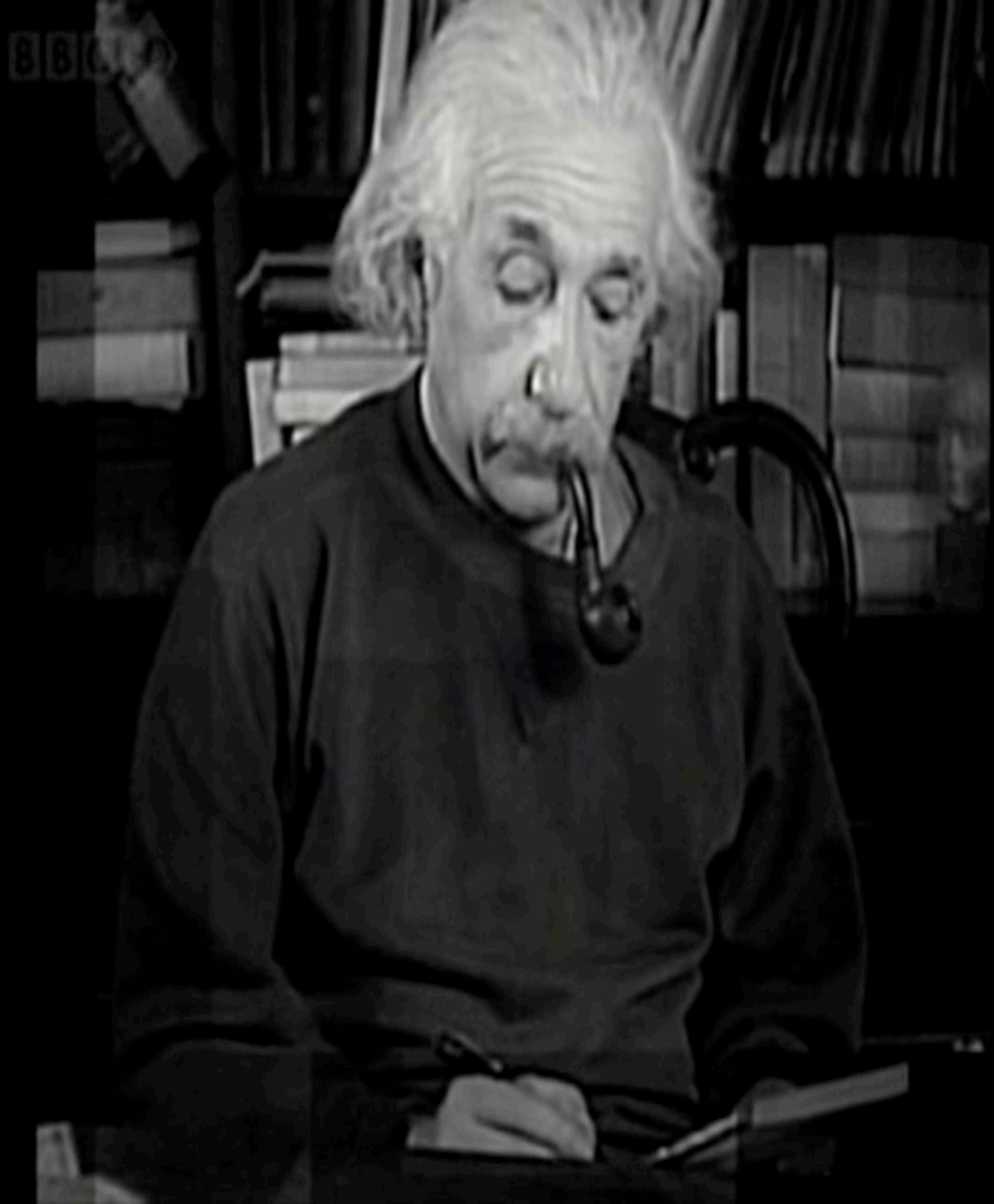
numbers

Chapter 5:

**What about
gravity?**

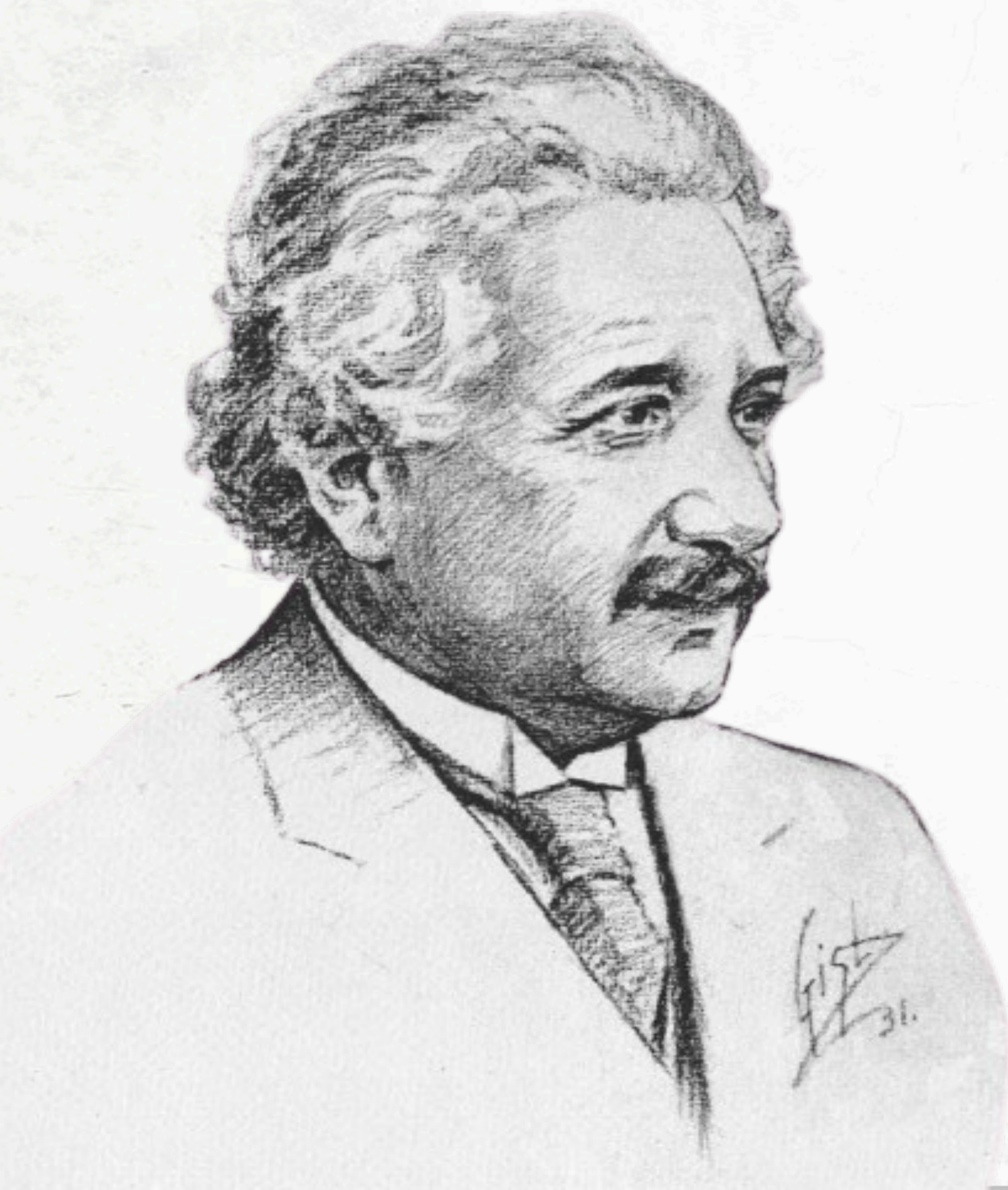


Albert Einstein



Why Einstein did not believe that general relativity geometrizes gravity

Dennis Lehmkuhl^{a,b,c}  

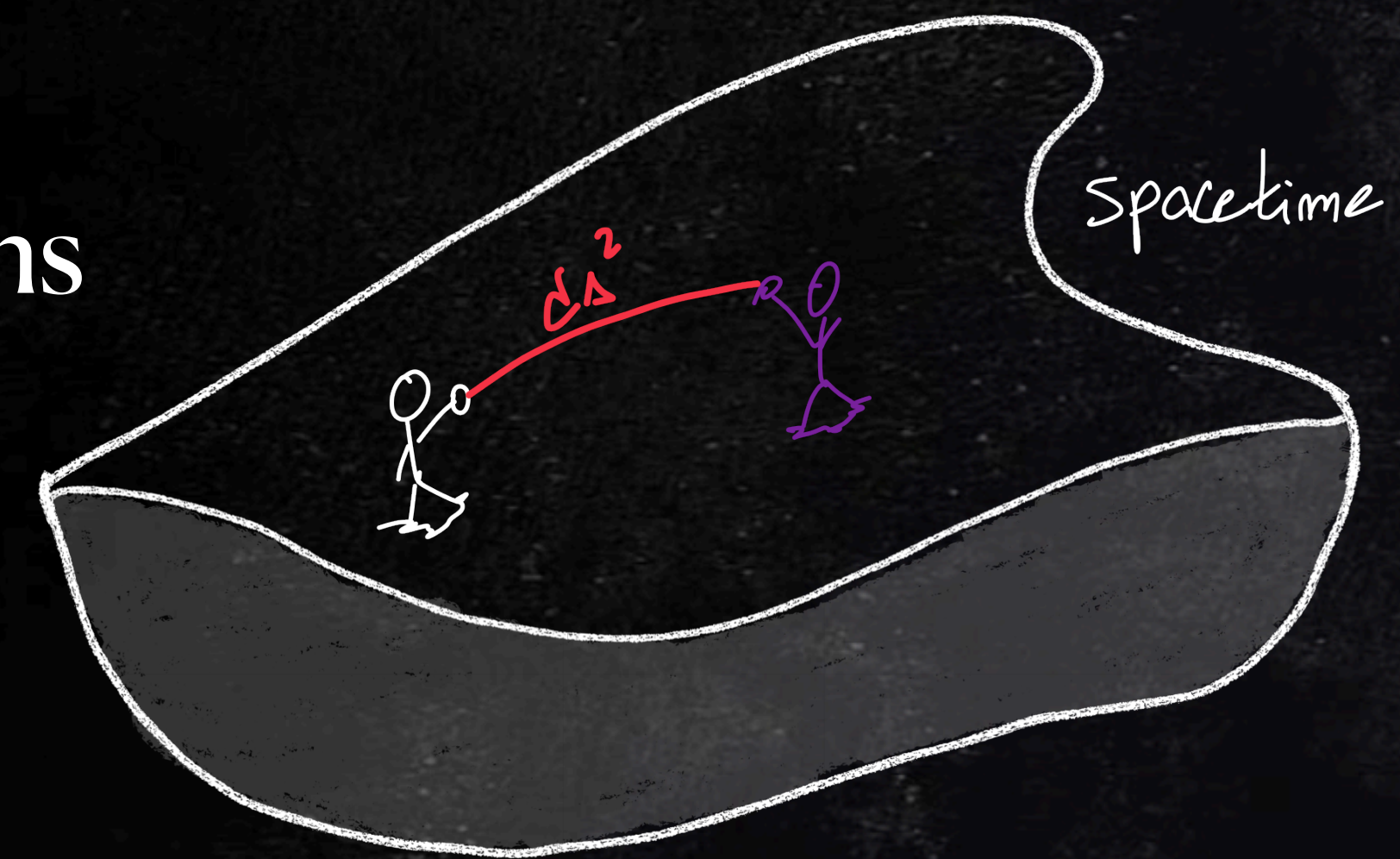


The picture of geometry as the study of the possible positions of displacements of rigid bodies already occurs four years earlier, in a text from December 1919/January 1920, which Einstein had intended as a paper for *Nature*, telling the story of how he recalled the historical development of both special and general relativity.²⁷

The systematic decoupling of basic geometrical concepts (straight line, distance, etc.) from the bodies of experience, of which they are abstract representations, must not let us forget that in the end geometry is supposed to tell us about the behavior of the bodies of experience. If there were no practically rigid bodies that can be brought into congruence with one another, we would not speak of the congruence of distances, triangles, etc. It is clear that for the physicist geometry becomes meaningful only as he associates bodies of experience with those basic concepts, for example by associating the concept of distance with a practically rigid body with two markings. Vice Versa, this association makes Euclidean geometry a science of experience in the truest sense, just like mechanics. The sentences of geometry can then be confirmed or falsified, just like the sentences of mechanics.

Relationalism:

Space and time *do not exist* as independent substances, there is only the material content of the universe. Space and time are merely defined through spatiotemporal relations among the material objects in the universe (and their parts). Spacetime is thus a (constructed) relational complex of relative positions of material objects.

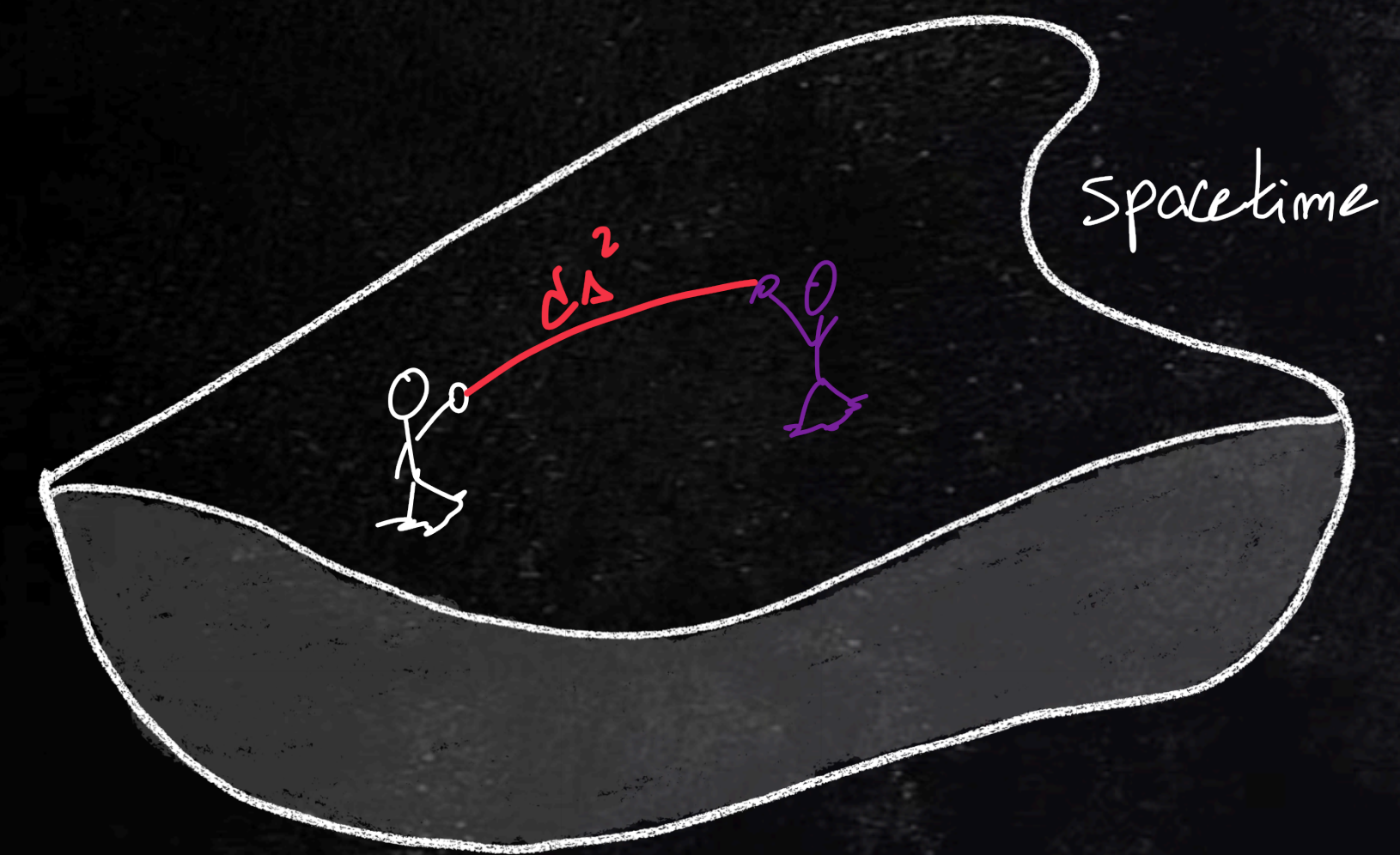


General Relativity

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

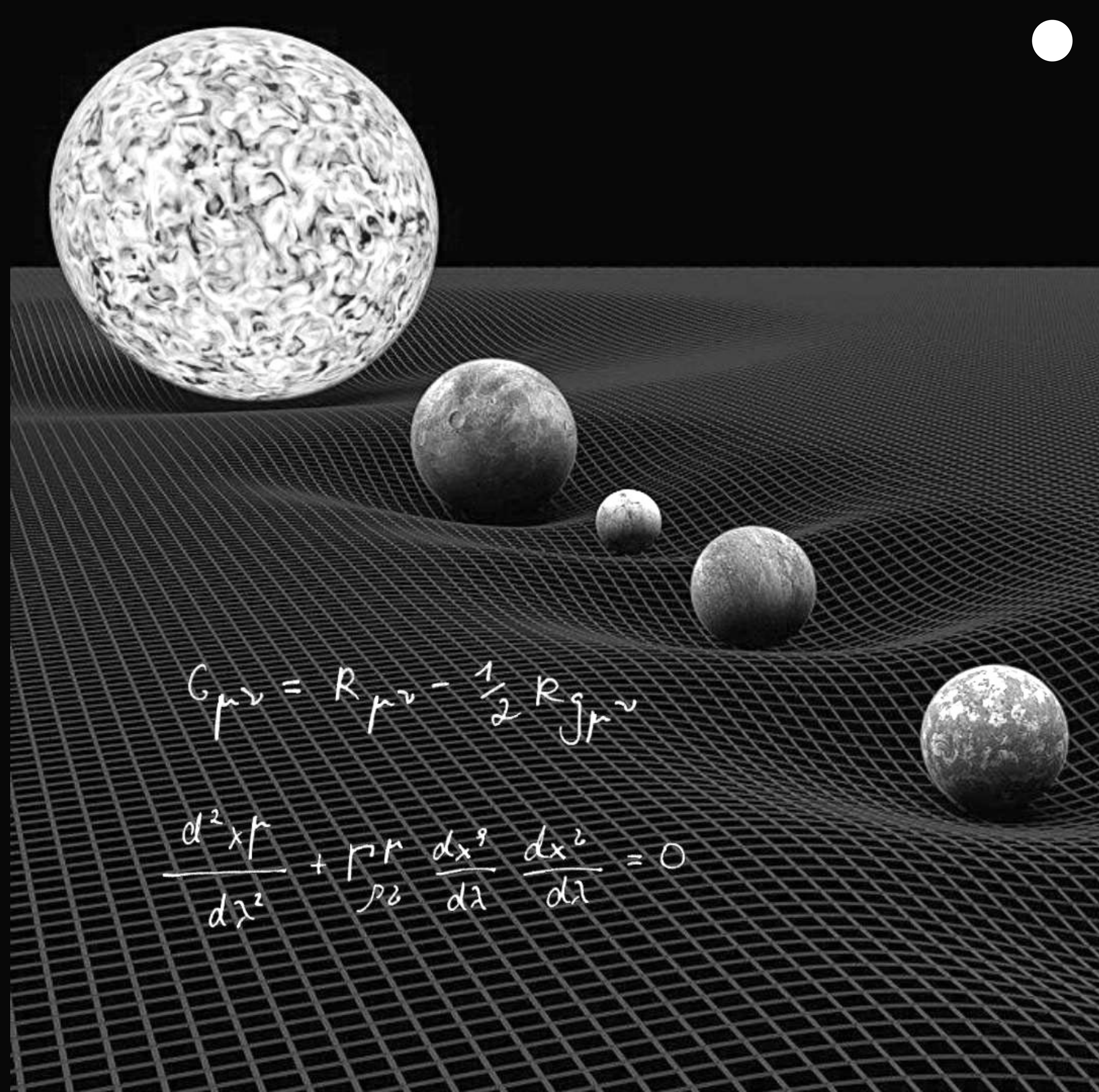
$$\frac{d^2x^\mu}{d\lambda^2} + \Gamma^\mu_{\rho\sigma}\frac{dx^\rho}{d\lambda}\frac{dx^\sigma}{d\lambda} = 0$$

It doesn't quite fully realize relationalism, and overall Einstein's project, as it still allows for vacuum (no matter) solutions.



What have we learned so far?

- Universality
- Operational Measurement Limitation
- **No local observables in QG**
- Holography
- Status-of-art...



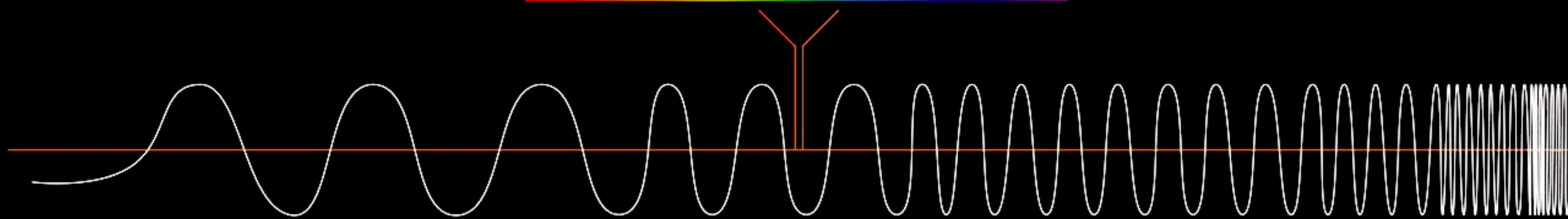
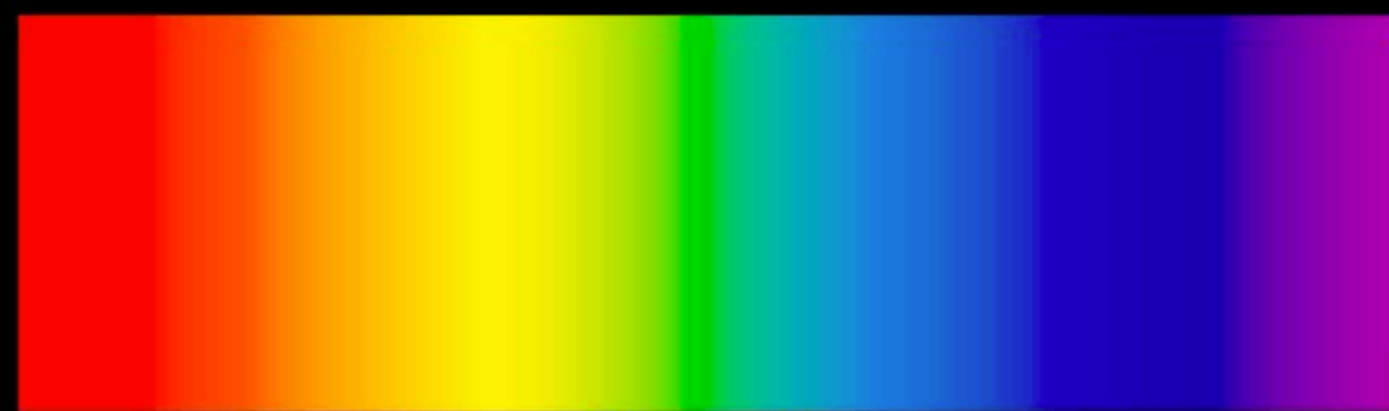
Universality I

**Universal scope
and universal
strength.**

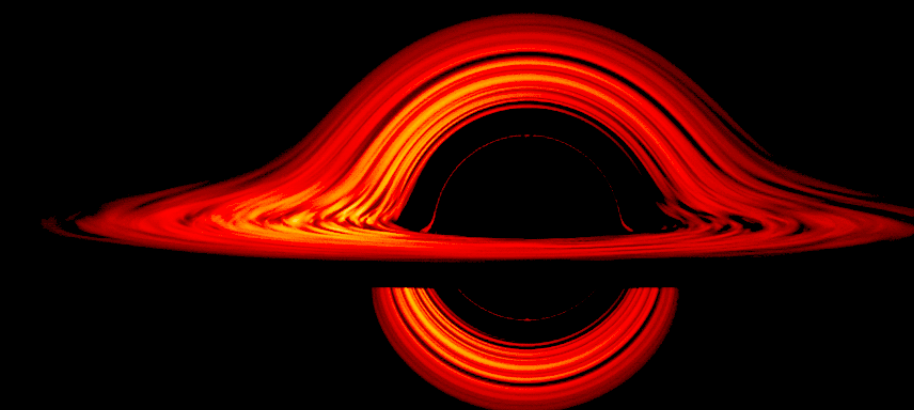


"The fact of a universal attraction might remind us of the situation in molecular physics; we know that all molecules attract one another by a force which **at long distances** goes like $1/r^6$. This we understand in terms of dipole moments which are induced by fluctuations in the charge distributions of molecules... Well, one possibility is that gravitation may be some attraction due to similar fluctuations in something, we do not know just what..."

Operational Measurement Limitation



RADIO (... - mm)	MICROWAVE (m - mm)	INFRARED (mm - 800 nm)	VISIBLE (800 nm - 400 nm)	ULTRAVIOLET (400 nm - 10 nm)	X-RAY (10 nm - 10^{-12} m)	GAMMA (10^{-12} m - ...)
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Higher Frequency & Energy

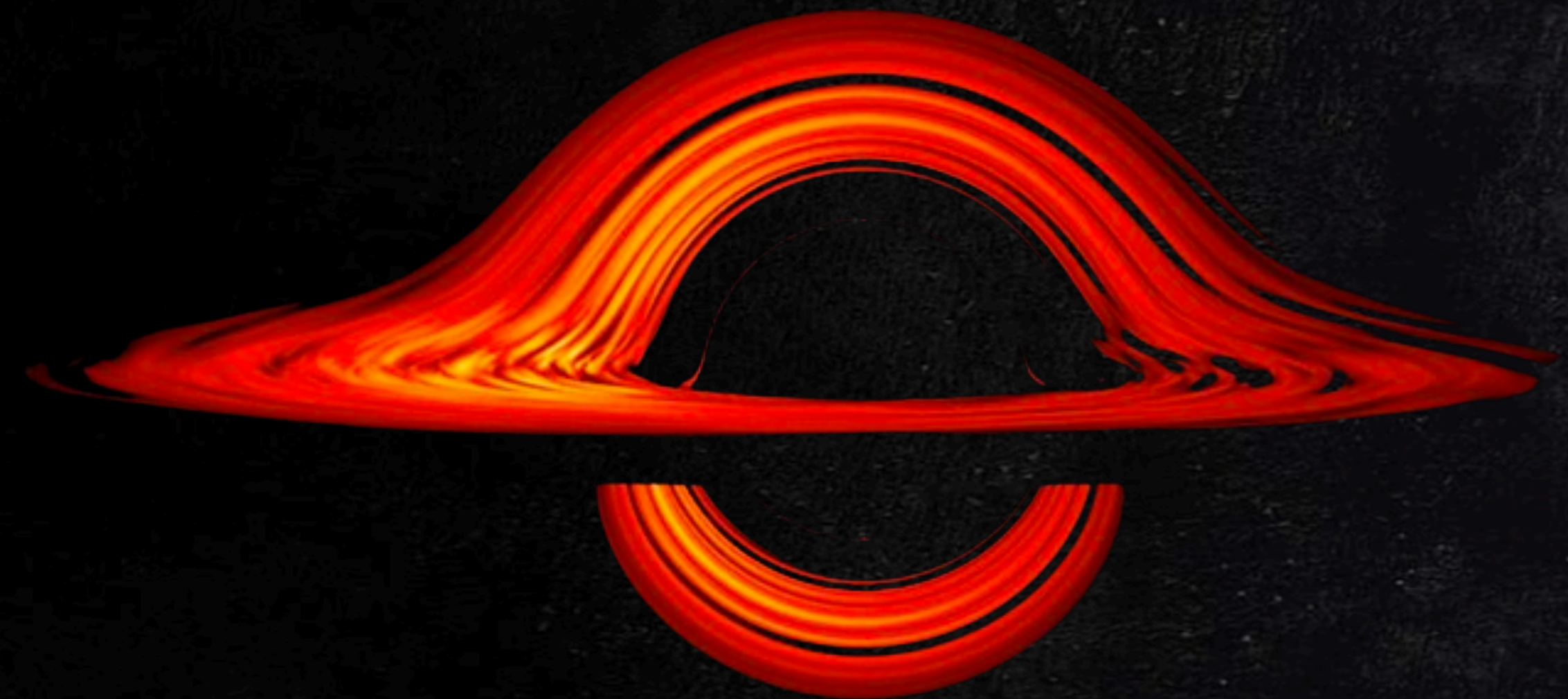
No local observables in Quantum Gravity

Black Holes are the most informatics-dense objects in the Universe. And the amount of information they can store is finite and scales as $e^{-A/G}$.

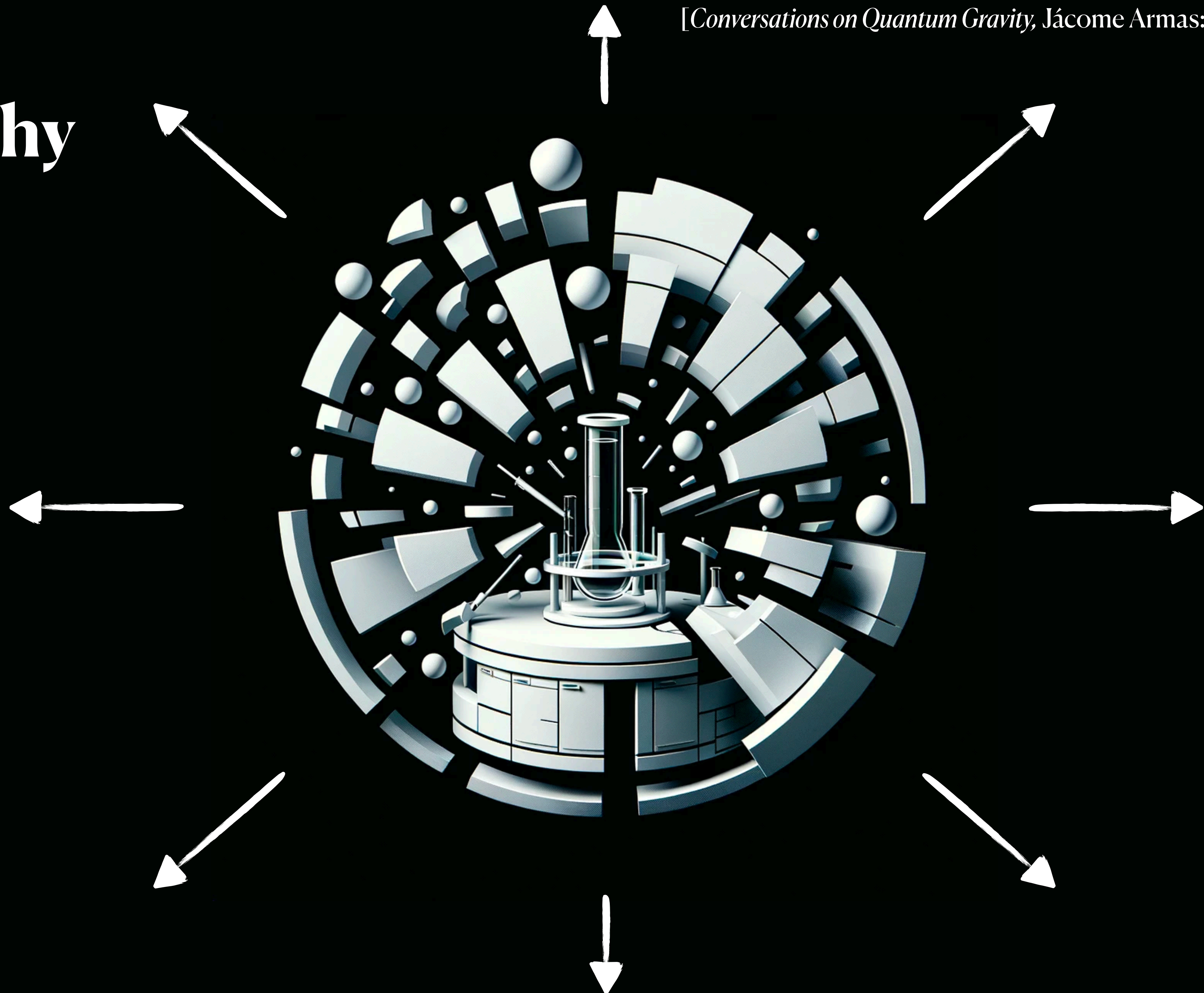
Thus, there is an intrinsic limitation on the amount of degrees of freedom locally available to perform any experiment.

Therefore, there is no precise observable one can associate with any measurement performed in a finite-size room.

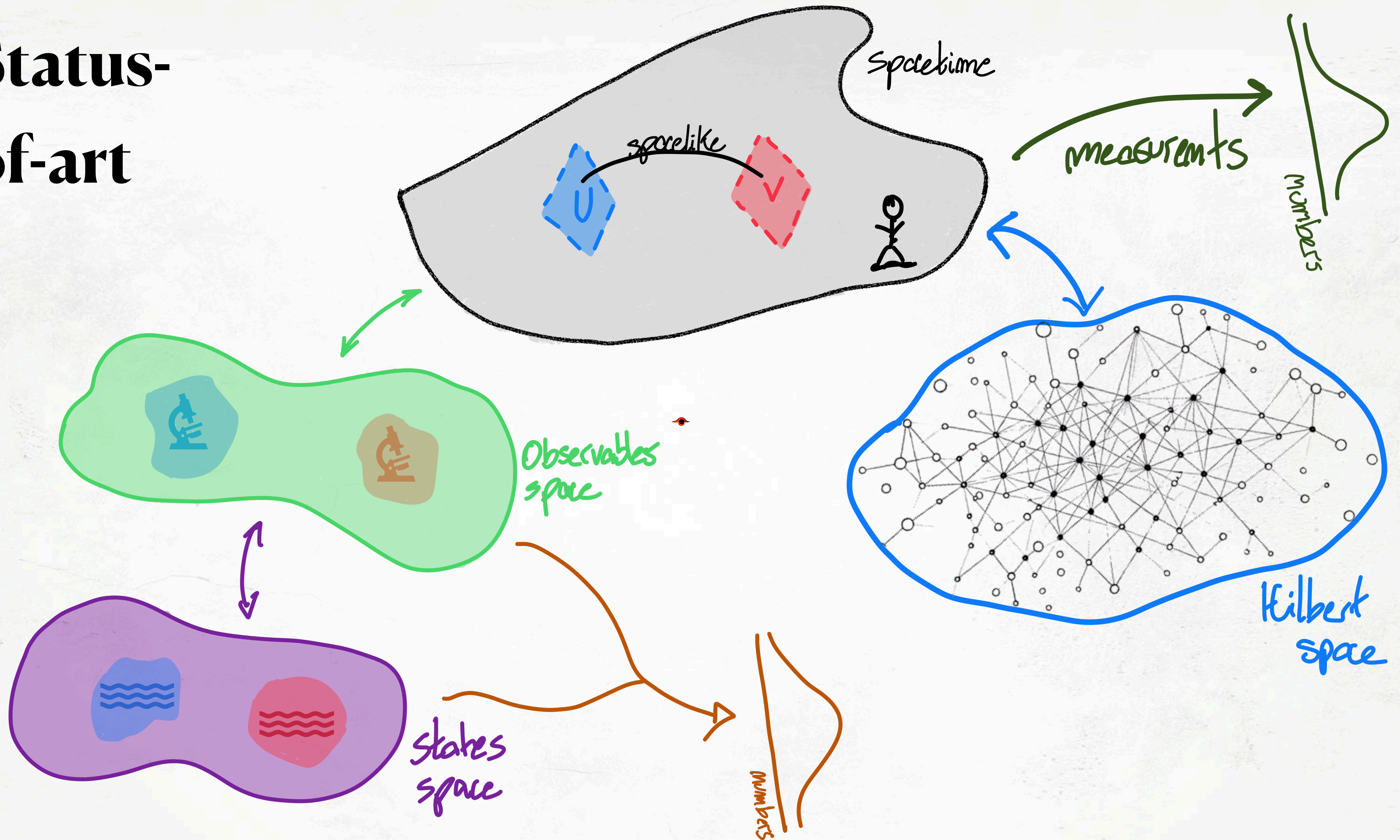
Unless...



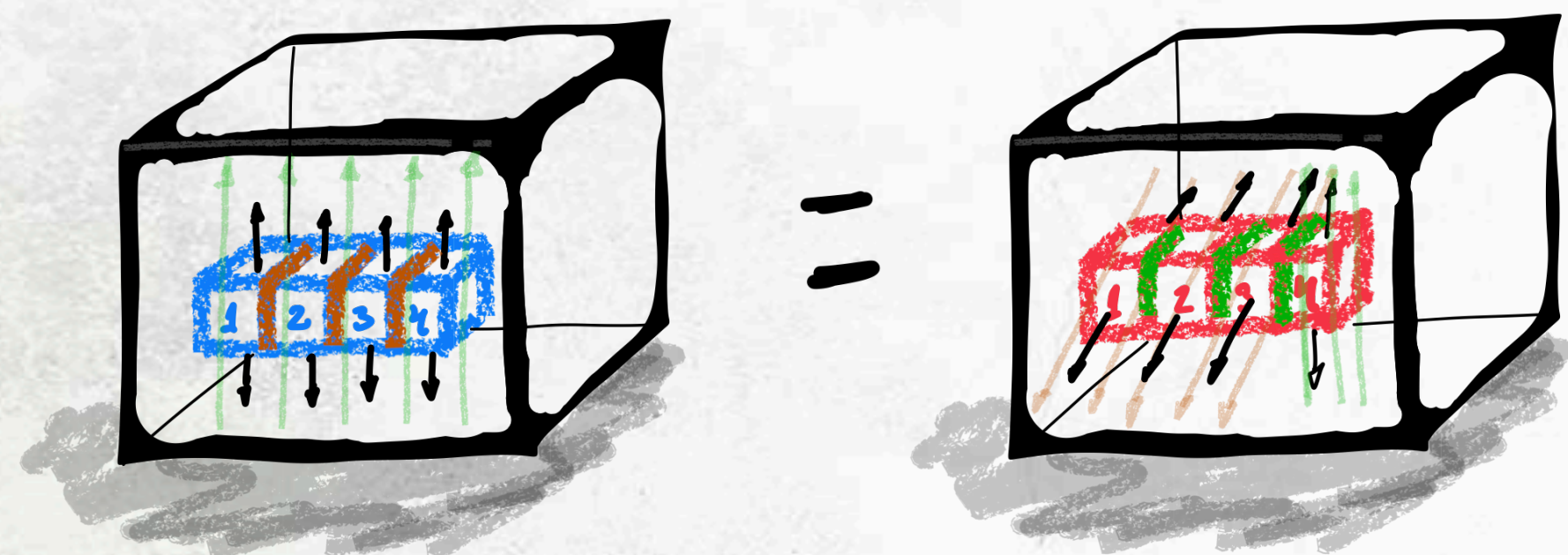
Holography



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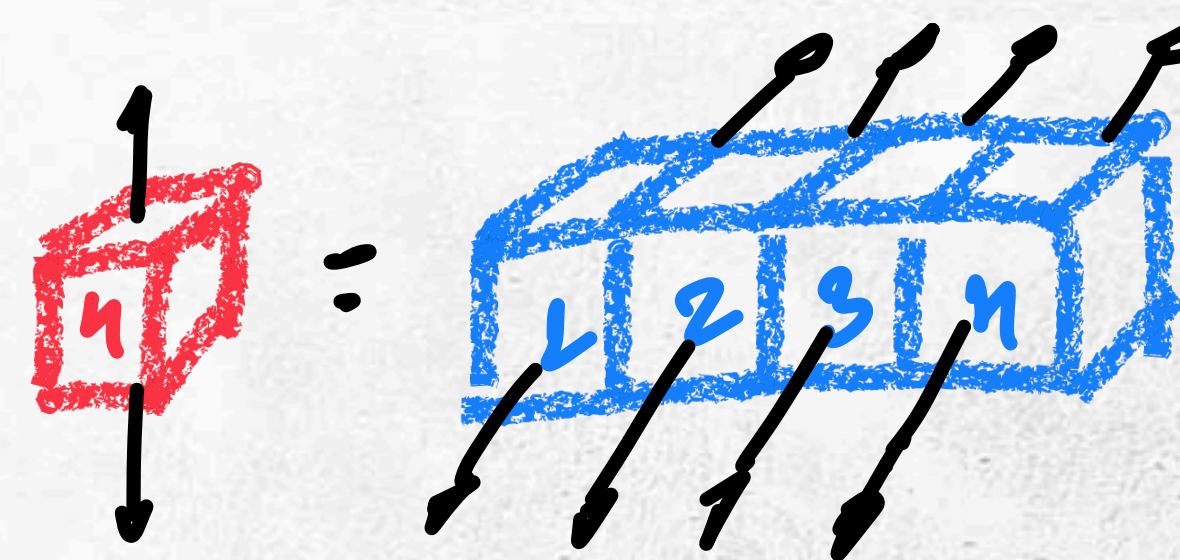
$$H = J \sum_{i=1}^{n-1} \sigma_i^z \sigma_{i+1}^z + h \sum_{i=1}^n \sigma_i^z = J \sum_{i=1}^n \mu_i^x + h \sum_{i=1}^{n-1} \mu_i^z \mu_{i+1}^z - J \mu_n^x + h \mu_1^z$$



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So, which one is it? How do we find out?

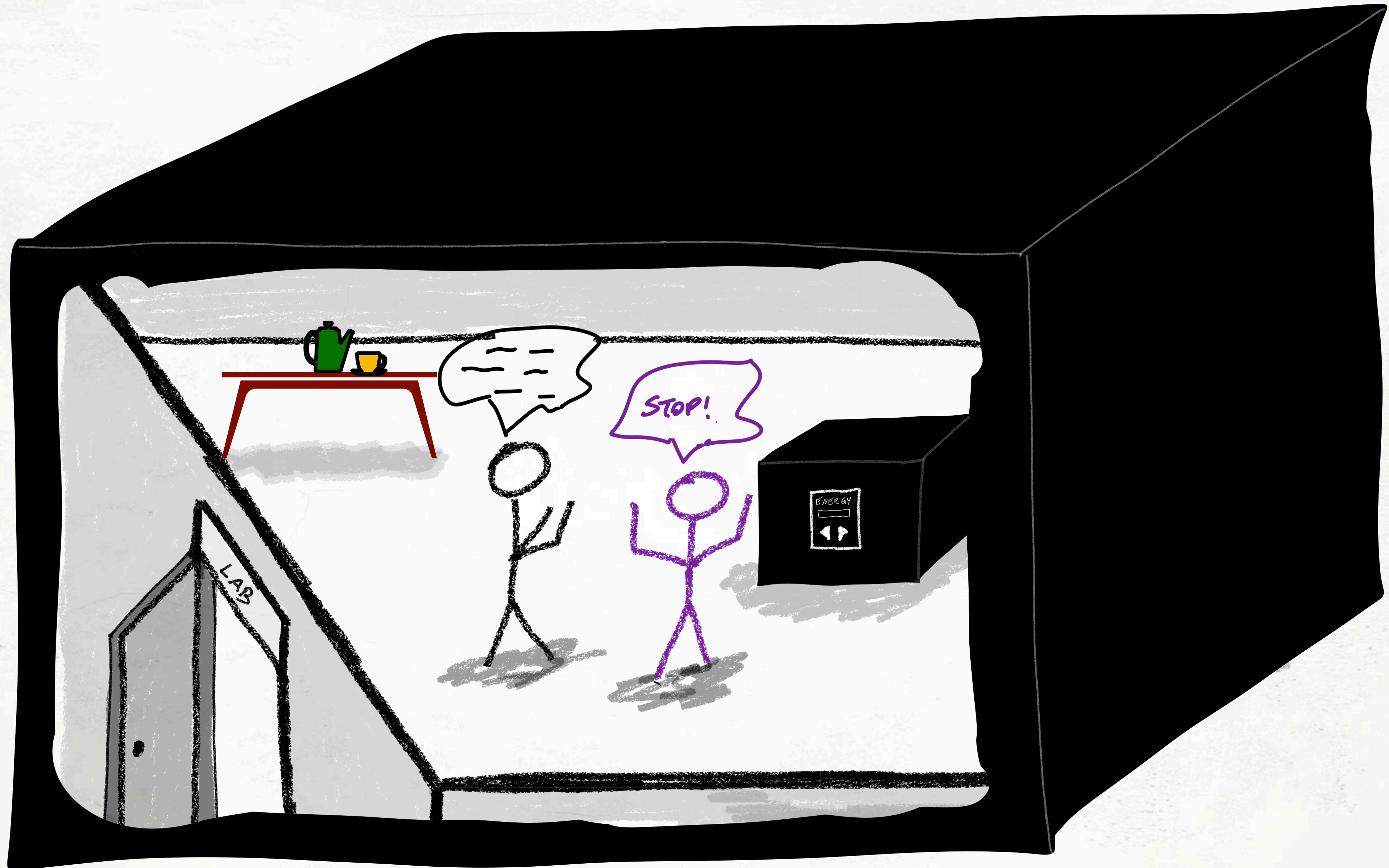
What if you cannot open the box?



We see that each description of what's inside assumes a different notion of the system, different notion of which parts are interacting, and therefore different notion of what's a neighboring site!

How do we make sense of that?

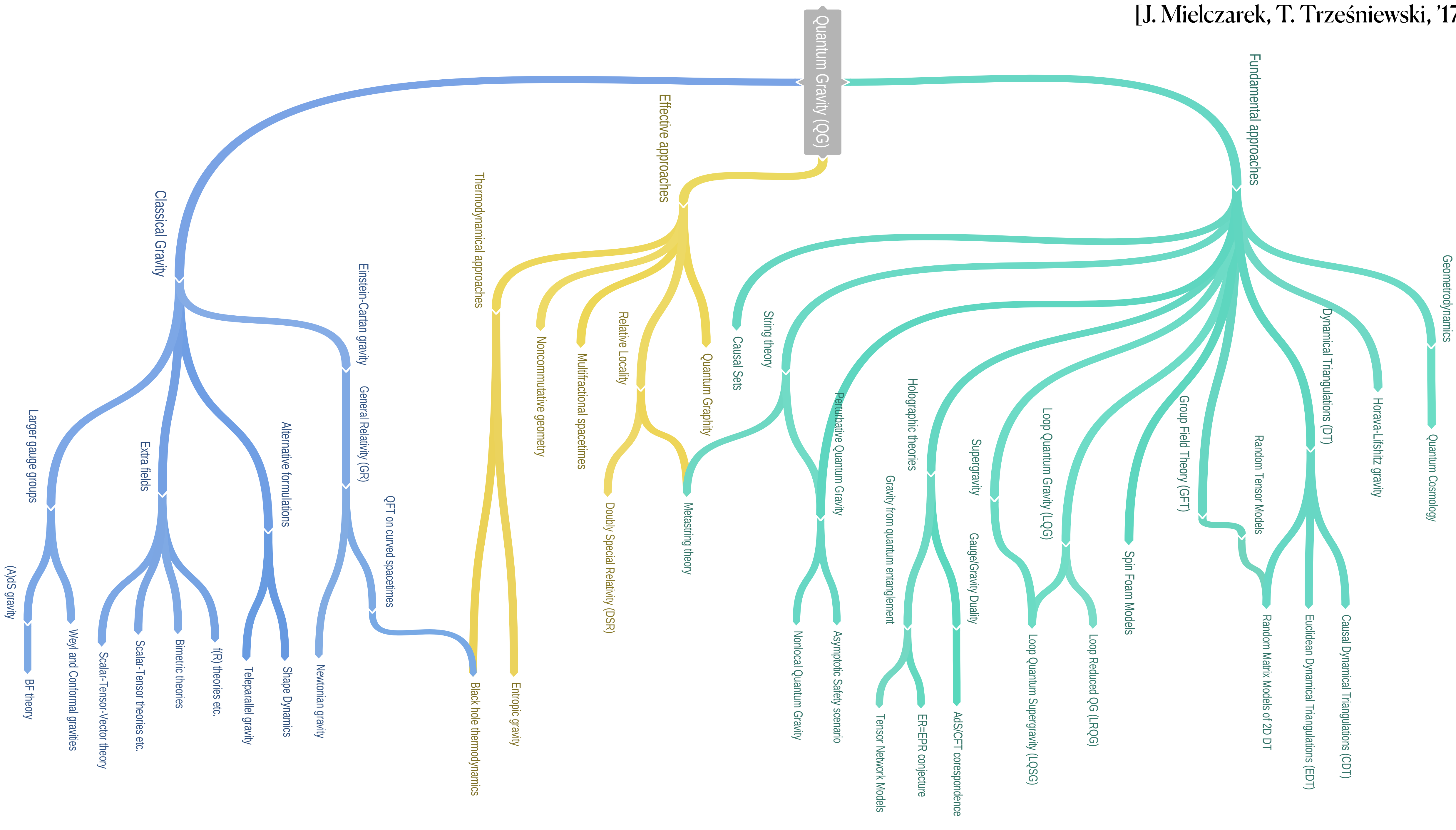
You thought these were the questions all along, but...



Chapter 6:

So now

what?



Oriti's levels of spacetime emergence

lvl. 0: gravity is classical!

Oriti's levels of spacetime emergence

lvl. 2.1: GR, quantization of geometric DOFs



Take the classical limit

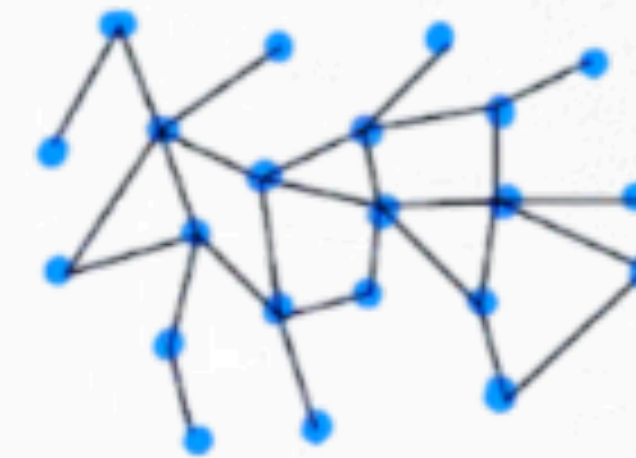
Oriti's levels of spacetime emergence

lvl. 2.1: GR, quantization of geometric DOFs



Take the classical limit

lvl. 2.2: fundamental DOFs combinatorial, algebraic (“atoms” of spacetime)



Take the continuum limit

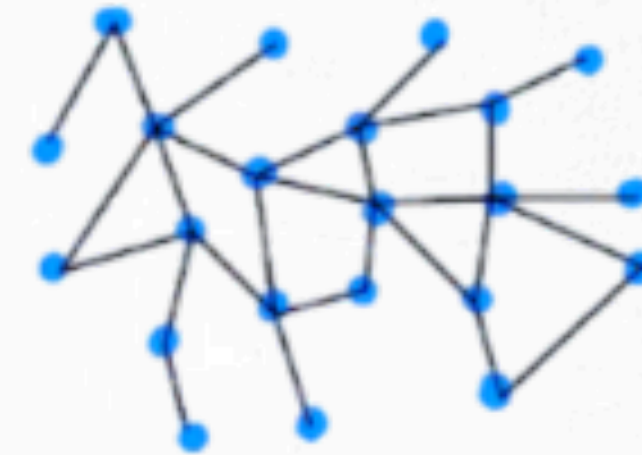
Oriti's levels of spacetime emergence

lvl. 2.1: GR, quantization of geometric DOFs



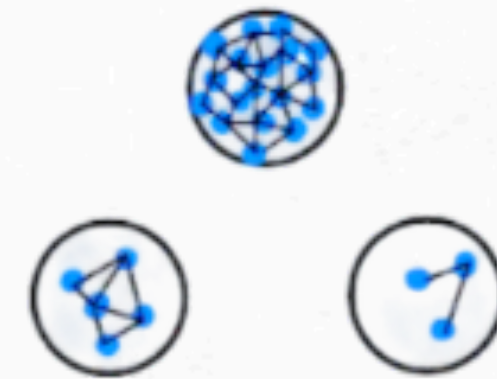
Take the classical limit

lvl. 2.2: fundamental DOFs combinatorial, algebraic (“atoms” of spacetime)



Take the continuum limit

lvl. 2.3: same DOFs, different phases, some non-geometrical



Show the existence of spacetime phase

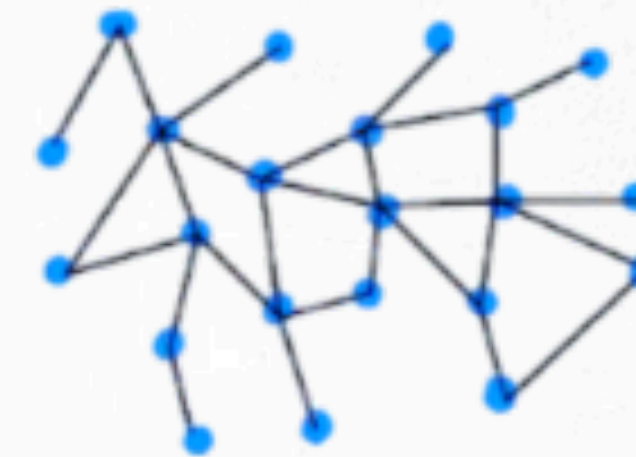
Oriti's levels of spacetime emergence

lvl. 2.1: GR, quantization of geometric DOFs



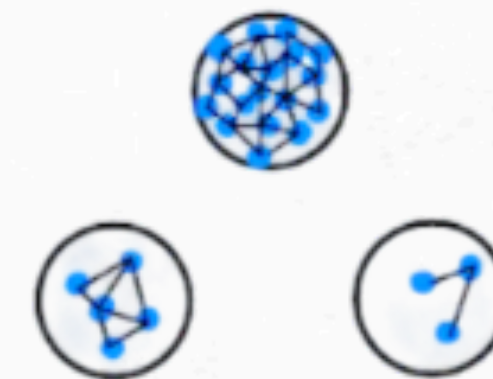
Take the classical limit

lvl. 2.2: fundamental DOFs combinatorial, algebraic (“atoms” of spacetime)



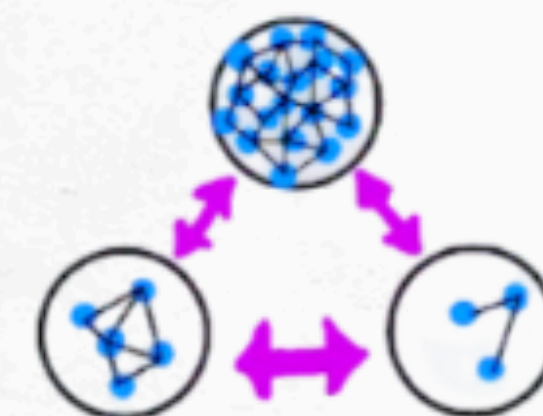
Take the continuum limit

lvl. 2.3: same DOFs, different phases, some non-geometrical



Show the existence of spacetime phase

lvl. 2.4: phase transitions, non-temporal **geometrogenesis**



Understand phase transitions

Thoughts

If no spacetime, but matter, **what does it mean to be matter?** Cannot be understood in the traditional way, in the sense of existing “in spacetime”, since it seems that the verb *to be* suddenly is not about “to be in spacetime” anymore, but rather “to be in quantum (Hilbert) space”.

At the same time, measurements happen in classical spacetime. So, it seems that one cannot let go of the classical anchoring and its role in defining the relevant ontology:

"one has to accept a multi-level ontology of some sort, in which both fundamental and emergent properties and entities are real in an appropriate sense." (Oriti, '18)

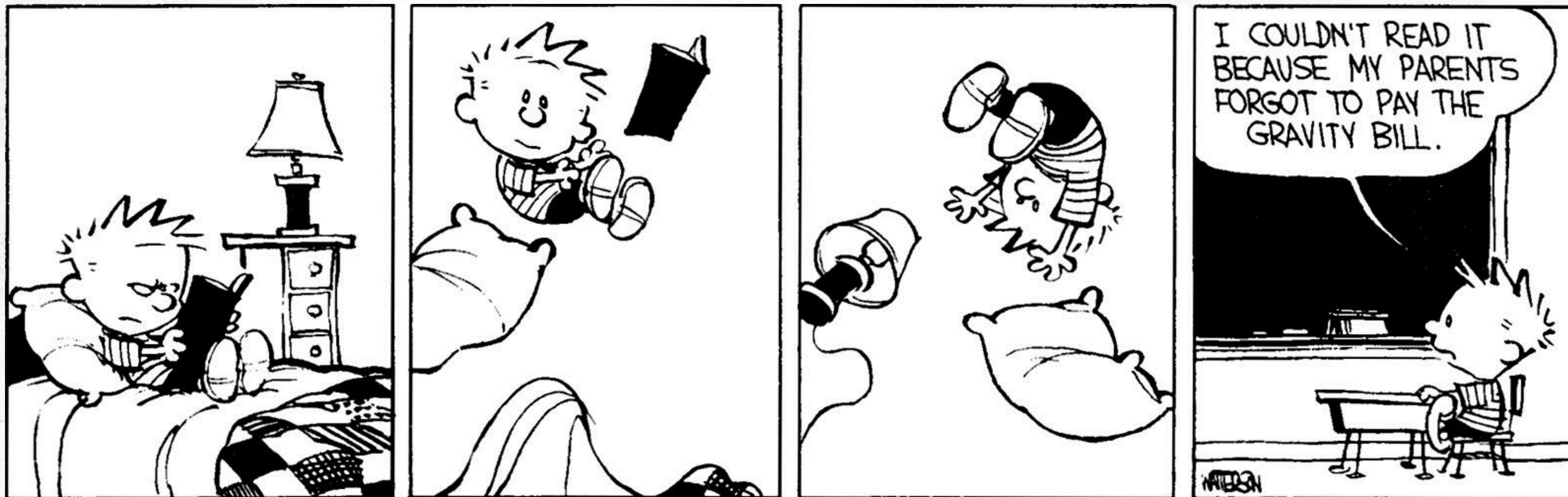
Conclusion

Progress can be typically made when *obvious* notions are finally put into question.

Among the historical remarkable examples, perhaps Einstein's scrutinizing of the nature of simultaneity leading to the theory of relativity and Planck's debunking of the radiation energy spectrum continuum giving rise to quantum mechanics stand out the most.

Another seemingly obvious concept is the idea of *what there is* - of independent physical systems. Combining relativity and quantum mechanics challenges the immediate naive understanding of how to describe different interacting physical systems.

This is a notion that, despite permeating all the physics we do, remains to be fully scrutinized in the context of quantum mechanics and the emergence of spacetime.



Thank you for the lovely
term together!