

# Side by Side

*Twenty-Four Models of the Universe*

Volume Six: Time, Life and Mind

Forrest Landry

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Links in the text name the book files of the physics collection of the Immanent Metaphysics and of the other volumes of this book, and they work when this book sits in the same folder as those files; *Category Theory and the Immanent Metaphysics* lies in the mathematics set.

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# Terms of the Collection

Each chapter of this book can be read alone. The terms below belong to the physics collection of the Immanent Metaphysics and are used across the chapters; they are defined here once, in the words the chapters use.

**Abiding.** In *The Weight of Possibility*, the share of a factor's curvature that holds fast in a registration as a term of its own, and by which it reduces a count of classes.

**Arena.** The context of physics, the geometry of space and time within which content is found; on the collection's account, what gravitation is.

**Axioms.** The three axioms of the Immanent Metaphysics, stated in *An Immanent Metaphysics*, aphorism 1.3-1, concern the three modalities. The first axiom holds that the immanent is more fundamental than the omniscient and the transcendent, and that the omniscient and the transcendent are conjugate to one another. The second axiom is the directed cycle of the three roles of comparison, an order of precedence and not of clock time, converging from many to one at each step. The third axiom makes the three distinct, inseparable and not interchangeable. The first axiom was formulated before the Incommensuration Theorem, and the theorem was afterward shown to entail all three.

**Bound triple.** The arrow of time, hard randomness and the subjective, distinct, inseparable and not interchangeable; consciousness is the bound triple taken as one act.

**Content and context.** In every comparison, what is found and the arena it is found in; in physics, quantum matter and the geometry of general relativity.

**Content instance and context instance.** The two instances of the internal space: as content it has no size and carries no spectrum of masses; as context it has radii, and its six directions are held at the modal boundary.

**Decoherence.** The spreading of the relative phase of two alternatives into an environment that registers which alternative is the case, after which they no longer interfere in measurements on the system alone.

**Entangling phase.** The phases of the two joint alternatives in which both masses are near or both far, less the phases of the two in which one is near and the other far.

**Far region.** The region far from the bodies, where the geometry of every alternative is flat and one measure of time serves them all; the collection's common term for the phase of two alternatives.

**Finding.** An interaction that registers which alternative is the case, made by any comparer, an instrument or an environment, with no mind needed.

**Gathered.** Said of choice: brought together from many acts of comparison into one persisting stance. "A photodiode's single undetermined click is choice at its least gathered; a living person is choice gathered across every channel of perception into one persisting stance".

**Gyration.** The unit of the dark matter on the collection's account: a conserved excitation of the six held internal dimensions, of about the Planck mass.

**Hard randomness.** An outcome that no prior specification fixes, however complete.

**Held.** Kept at the same size and shape at every point, as the six internal dimensions are, each standing at the modal boundary.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. It is a structural fact about the nature of knowing.

**Modal boundary.** The Planck curvature, at which the descriptions of content and context exchange dominance.

**Modalities.** The three roles of comparison: the immanent (held in the act), the omniscient (held as structure laid out), the transcendent (implicit, held in the stance). In the example the Bohr chapter uses, the measurement is immanent, the particle omniscient and the wave transcendent.

**Order of depth.** Metaphysics, physics, computation, mathematics, ordered by what each presupposes.

**Per-alternative geometry.** Each alternative of the matter carries its own classical geometry, and the relative phases of the alternatives are kept.

**Performed, surveyed, implied.** The three ways a claim can be held: by what happens in the act of engaging it; from a vantage with many cases in view; in the stance a practice proceeds from.

**Planck curvature.** The curvature whose radius is the Planck length, the scale at which an object's gravitational size equals its quantum size; it is not a least length.

**Root Tautology.** Comparison, interaction and relation are one act under three names.

**Rule of decision.** The rule of the registered predictions: a result counts when it is established at five standard deviations by at least two independent kinds of measurement.

**Sealed prediction.** A prediction as worded in the collection's dated register, fixed before the measurement that decides it is made.

**Sealed record.** *The Registered Predictions of Physics from Comparison; A Dated Record, 1 November 2026*, fixed at its date and not revised.

**Short names.** "The Passage" is *The Gravitational Passage*; "the Companion" is *The Gravitational Companion*; "the collection" is the physics collection of the Immanent Metaphysics, also called physics from comparison.

**Six internal dimensions.** The internal space $\mathbb{C}P^2 \times S^2$, a complex projective plane and a sphere, also called the six dimensions of possibility; held at the modal boundary, they are the range from which each finding is one selection, and nothing travels through them.

**Six intrinsics.** The parts of every comparison, in three pairs: same and different, content and context, the subjective and the objective. The Deutsch chapter calls a different set of six, the grid of six measures every comparison carries, by its own name.

**Stance.** The side from which a comparison is made; it belongs to every comparison, human or not.

**Structural arrow.** The direction of time as the direction in which comparison proceeds: from the range of what could be found, to the act, to the record.

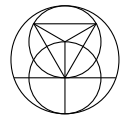
**Superdeterminism.** A deterministic completion of quantum mechanics in which the settings of an experiment are fixed together with the states of what is measured, so that statistical independence fails.

**The turn.** The passage from the end of one epoch of the universe to the beginning of the next, at the end of every black-hole interior; no comparison registers it as an event.

**Three ways of validation.** Measurement (first person), agreement (second person) and proof (third person); only measurement and proof validate truth.

FROM VOLUME ONE

# WHERE THE ACCOUNTS PART



Section I

# Twenty-Four Models, One Record

*I reprint this section, and the tables of Section XVI, from Volume One, so that each volume can be read alone.*

Every account of physics makes a claim about the universe. Most accounts are theories of one part of the universe, such as the quantum or gravitation or the dark matter or the mind. The quantum is the behavior of matter and light at the scale of atoms and smaller. The dark matter is matter that is known only by its gravitation. I set twenty-four accounts of physics side by side, the twenty-four models of the book's title, and I compare each model with a single record of forty-two predictions.

The record is *The Registered Predictions of Physics from Comparison* (DOI https://doi.org/10.67291/RQQS3025), a register of forty-two predictions that I sealed on 1 November 2026: I fixed the wording of the register on that date, and I do not revise the register. I therefore call the register the sealed record. The sealed record says what experiment and observation will find for each of the forty-two predictions: for example, whether two masses become entangled through gravitation, what the ratio of the dark matter to the ordinary matter is, whether the equation of state of the vacuum is exactly $-1$, and whether any new kind of particle will be found. Entangled masses are masses whose quantum states are linked, so that neither mass can be described on its own. The equation of state of the vacuum is the ratio of the pressure of empty space to the energy density of empty space. The equation of state is exactly $-1$ for a cosmological con-

stant, which is an energy of empty space that never changes. For each prediction, the sealed record also says what measurement decides the prediction.

The first of the twenty-four models is physics from comparison, the physics of the Immanent Metaphysics. The Immanent Metaphysics is the philosophy that I set out in my book *An Immanent Metaphysics*. The basis of physics from comparison is the Incommensuration Theorem, which is a structural fact about the nature of knowing: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The Immanent Metaphysics has three axioms, and I formulated the first axiom in or before 1991. I formulated the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996, and most of the physics in physics from comparison in 1997 and 1998. *An Immanent Metaphysics* was published in 2001. I set out physics from comparison in the books of the physics collection of the Immanent Metaphysics, called the collection for short. The predictions of physics from comparison are the sealed record.

Each of the other twenty-three models belongs to the scientist or scientists who built the model. Two of the twenty-three models are joint models, each built by two people. One joint model is an argument made by the physicists Chiara Marletto and Vlatko Vedral from constructor theory, which states the laws of physics as rules about which transformations are possible and which are impossible. The other joint model is modified Newtonian dynamics, a law of gravity that departs from Newton's law below a fixed value of acceleration. The physicist Mordehai Milgrom founded modified Newtonian dynamics, and the astronomer Stacy McGaugh has continued Milgrom's work on modified Newtonian dynamics. Some of the twenty-three models are models of the whole universe, while others are models of something that the whole universe contains: of the quantum, of the cosmos, or of life and mind. In each chapter I credit the model plainly: I say where the model was the first to obtain a result, and where measurement has borne out a result of the model.

Some other accounts of physics appear in the chapters only in passing. One such account is the physicist Carlo Rovelli's relational quantum mechanics, in which a quantum state describes how one system is related to another. Another is Bohmian mechanics, in which every particle has a definite position at every moment. Two more are QBism, the reading of quantum probabilities as an agent's degrees of belief, and the string program, the research program of string theory, in which the smallest parts of matter are tiny vibrating strings. I leave for later the work of setting relational quantum mechanics, Bohmian mechanics, QBism and the string program beside physics from comparison.

You, the reader, keep the score. I set out where each model disagrees with physics from comparison and what will decide each disagreement, so that you can count the decisions as the decisions are made. I say that two models "part" at any step, premise or measurement that one model accepts and the other model rejects. For each of the other models, I can name in one sentence the step, premise or measurement at which the model parts from physics from comparison. Experiments now under way will settle, within years, several of the points at which the other models part from physics from comparison. In each chapter that follows, I set one model beside physics from comparison and find the step at which the two models part. In each chapter, at each parting, I say which of three possibilities holds for the two sides: the model of that chapter and physics from comparison. The first possibility is that one side takes a step that does not follow from the premises of that side. When the first possibility holds, I give a case that shows the failure of the step. The second possibility is that the steps of both sides follow and the two sides start from different premises, and in that case I state the difference between the premises in one sentence, together with what settles the difference. The third possibility is that a measurement already made contradicts the premise of one side. Each chapter has a register, printed as an appendix of the volume that holds the chapter, that sets the predictions of the chapter's model beside the sealed record.

## How the book is laid out

Part One, the first part of this book, holds the disputes between the models, one short section for each dispute, and the tables that give every model's answer to every question. In each part after Part One, every model has a separate chapter. I have grouped the models into parts by the question each model bears on most. Within each part, the chapters come in the order in which the models were put forward; Part Six alone takes its three models of time first, and its models of life and of mind after them.

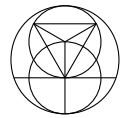
The book is printed in six volumes, and each part fills one volume. Volume One, The Questions and the Record, holds Part One and the sealed record itself, the register of forty-two predictions. Volume Two, Chance, Determinism and Measurement, holds Part Two, with the models of Niels Bohr, Gerard 't Hooft, Nicolas Gisin, Anton Zeilinger and Sabine Hossenfelder. The models of Part Two are models of what a finding is, what the quantum state is, and whether the world is determined. A finding is an interaction that registers which of several alternatives is the case. An instrument or an environment can make a finding, with no mind needed. The quantum state is the complete quantum description of a system.

Volume Three, The Quantum and the Arena, holds Part Three, with the models of Roger Penrose, Chiara Marletto and Vlatko Vedral, Sean Carroll, and Jonathan Oppenheim. The models of Part Three are models of what gravitation does to a superposition. A superposition is a quantum state that is a sum of alternatives, such as a body in two places.

Volume Four, Discreteness and Computation, holds Part Four, with the models of John Archibald Wheeler, David Deutsch, Max Tegmark and Stephen Wolfram. Volume Five, The Cosmos and the Dark Component, holds Part Five, with the models of Arthur Eddington, George Ellis, Mordehai Milgrom and Stacy McGaugh, and Erik Verlinde. Volume Six, Time, Life and Mind, holds Part Six, with the models of Julian Barbour, Lee Smolin, Ilya Prigogine, Robert Rosen, Giulio Tononi and Karl Friston.

The lists of Parts Two to Six give the names of the scientists who built the other twenty-three models. Each model's chapter says who built the model and what the builders did.

The prediction matrix is the first appendix of each volume. The prediction matrix of Volume One sets all twenty-three other models beside the sealed record, and the prediction matrix of each later volume sets the models of that volume beside the sealed record. The prediction matrix has one row for each of the forty-two sealed predictions: each row lists the models that agree with the prediction and the models that differ from the prediction. After the prediction matrix, the register of each person's model follows as a separate appendix, in the volume that holds the chapter on that model.



Section XVI

# Where Each Model Stands

In each of the tables below, every one of the twenty-four models has a row, and every column after the first asks one question. Each cell gives one model's answer to one question, in a few words, as the chapter on the model states the answer. Volumes Two to Six hold the chapters on the twenty-three other models, and this volume holds the chapters on the models of Julian Barbour, Lee Smolin, Ilya Prigogine, Robert Rosen, Giulio Tononi and Karl Friston. Where a cell reads "silent", the model in the cell's row makes no claim about the question in the cell's column. The first row of every table gives the answers of physics from comparison, which is the physics of the Immanent Metaphysics and is the first of the twenty-four models.

## The quantum and gravitation

| Model | Is the geometry quantized? | Does gravity entangle two masses? | Does a superposition end of its own accord? |
|---|---|---|---|
| Physics from comparison | No; the geometry is the context | Yes, phase 0.314 radians | No; only a finding ends one |
| Bohr | silent | silent | silent |

| Model | Is the geometry quantized? | Does gravity entangle two masses? | Does a superposition end of its own accord? |
|---|---|---|---|
| Deutsch | Yes; the field is one more system | Yes | No |
| Penrose | Not in the usual way | No; collapse comes first | Yes, about 0.012 seconds |
| 't Hooft | silent | silent | silent |
| Gisin | silent | silent | Yes; collapse is real |
| Zeilinger | silent | silent | No |
| Hossenfelder | silent | silent | silent |
| Marletto and Vedral | Yes, as a non-classical mediator | Yes | silent |
| Carroll | Yes; space emerges from the state | Yes | No |
| Oppenheim | No; classical, with diffusion | No | Yes; decoherence with diffusion |
| Wheeler | Yes, at every scale | Yes | No |
| Barbour | Yes; one more configuration | silent | No |
| Smolin | Yes; discrete area and volume | silent | silent |
| Tegmark | silent | silent | No |
| Wolfram | silent | silent | silent |
| Eddington | silent | silent | silent |
| Ellis | silent | silent | silent |

| Model | Is the geometry quantized? | Does gravity entangle two masses? | Does a superposition end of its own accord? |
|---|---|---|---|
| Milgrom and McGaugh | silent | silent | silent |
| Verlinde | No | silent | Yes, in models built on his |
| Prigogine | silent | silent | silent |
| Rosen | silent | silent | silent |
| Tononi | silent | silent | silent |
| Friston | silent | silent | silent |

## Steps, statistics and determinism

| Model | Is there a least length or a rule beneath? | Do the Born weights hold everywhere? | Is the world fully determined? |
|---|---|---|---|
| Physics from comparison | No; the arena is continuous | Yes, everywhere | No |
| Bohr | silent | Yes | No |
| Deutsch | silent | Yes | Yes, as a whole |
| Penrose | silent | silent | silent |
| ’t Hooft | Yes; a deterministic automaton | Yes | Yes |
| Gisin | silent | Yes | No |
| Zeilinger | silent | Yes | No |
| Hossenfelder | No energy-dependent speed | Correlations in time in her test | Yes; superdeterministic |

| Model | Is there a least length or a rule beneath? | Do the Born weights hold everywhere? | Is the world fully determined? |
|---|---|---|---|
| Marletto and Vedral | silent | Yes | silent |
| Carroll | silent | Yes | Yes, as a whole |
| Oppenheim | silent | silent | silent |
| Wheeler | Yes; a foam | Yes | silent |
| Barbour | silent | silent | silent |
| Smolin | Yes; steps, or a deformed symmetry | From the record of precedents | No |
| Tegmark | silent | Yes | Yes, across the many worlds |
| Wolfram | Yes; one discrete rule | Yes | Yes; one rule fixes all |
| Eddington | silent | silent | silent |
| Ellis | silent | Yes | No |
| Milgrom and McGaugh | silent | silent | silent |
| Verlinde | silent | silent | silent |
| Prigogine | silent | silent | No |
| Rosen | silent | silent | silent |
| Tononi | silent | silent | silent |
| Friston | silent | Yes | silent |

## The early universe and the dark matter

| Model | Did a long inflation happen? | Is space flat? | What is the dark matter? |
|---|---|---|---|
| Physics from comparison | No | Yes, to 10−5 | Gyrations of about the Planck mass |
| Bohr | silent | silent | silent |
| Deutsch | silent | silent | silent |
| Penrose | No; one epoch to the next | Begins even (Weyl curvature hypothesis) | Erebons of about the Planck mass, which decay |
| 't Hooft | silent | silent | silent |
| Gisin | silent | silent | silent |
| Zeilinger | silent | silent | silent |
| Hossenfelder | silent | silent | silent |
| Marletto and Vedral | silent | silent | silent |
| Carroll | Possibly, spawned from de Sitter space | silent | A dark force explored |
| Oppenheim | silent | silent | Diffusion of a classical geometry |
| Wheeler | silent | No; closed | silent |
| Barbour | silent | silent | silent |
| Smolin | silent | silent | silent |
| Tegmark | Yes, eternal | Yes | An axion, varying by region |
| Wolfram | silent | silent | silent |

| Model | Did a long inflation happen? | Is space flat? | What is the dark matter? |
|---|---|---|---|
| Eddington | silent | silent | silent |
| Ellis | One option among others | No; an emergent closed space | silent |
| Milgrom and McGaugh | silent | Yes | None in galaxies; the law changes |
| Verlinde | silent | silent | Apparent, from horizon entropy |
| Prigogine | silent | silent | silent |
| Rosen | silent | silent | silent |
| Tononi | silent | silent | silent |
| Friston | silent | silent | silent |

## Acceleration, vacuum and dimension

| Model | Is there a constant of acceleration? | Is the vacuum energy constant? | How many dimensions has space? |
|---|---|---|---|
| Physics from comparison | No; scale set by formation; no external field effect | Yes, exactly −1 | Three, by necessity |
| Bohr | silent | silent | silent |
| Deutsch | silent | silent | silent |
| Penrose | silent | Yes | silent |
| ’t Hooft | silent | silent | silent |
| Gisin | silent | silent | silent |
| Zeilinger | silent | silent | silent |

| Model | Is there a constant of acceleration? | Is the vacuum energy constant? | How many dimensions has space? |
|---|---|---|---|
| Hossenfelder | silent | silent | silent |
| Marletto and Vedral | silent | silent | silent |
| Carroll | silent | silent | silent |
| Oppenheim | silent | silent | silent |
| Wheeler | silent | silent | silent |
| Barbour | silent | silent | silent |
| Smolin | Yes; from the de Sitter temperature | silent | silent |
| Tegmark | silent | Yes | Three here |
| Wolfram | silent | silent | Emergent; may vary |
| Eddington | silent | Yes | silent |
| Ellis | silent | Perhaps an effect of inhomogeneity | silent |
| Milgrom and McGaugh | Yes; an external field effect | Yes | silent |
| Verlinde | Yes; set at the horizon | silent | silent |
| Prigogine | silent | silent | silent |
| Rosen | silent | silent | silent |
| Tononi | silent | silent | silent |
| Friston | silent | silent | silent |

## Time, mind and the constants

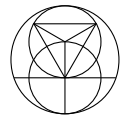
| Model | Where does the arrow of time come from? | What are life and mind to physics? | Can the constants be derived? |
|---|---|---|---|
| Physics from comparison | Beneath the laws, in the order of findings | Acts of comparison; the brain near criticality | Pure numbers of the structure; others measured |
| Bohr | silent | silent | silent |
| Deutsch | silent | silent | silent |
| Penrose | The even beginning of each epoch | Orchestrated reduction | silent |
| 't Hooft | silent | silent | silent |
| Gisin | silent | silent | silent |
| Zeilinger | silent | silent | silent |
| Hossenfelder | silent | silent | silent |
| Marletto and Vedral | Irreversibility in tasks | silent | silent |
| Carroll | A special past state | silent | silent |
| Oppenheim | silent | silent | silent |
| Wheeler | silent | silent | silent |
| Barbour | A Janus point; time not fundamental | silent | silent |
| Smolin | Time real; laws evolve | silent | silent |
| Tegmark | silent | silent | silent |
| Wolfram | silent | silent | silent |

| Model | Where does the arrow of time come from? | What are life and mind to physics? | Can the constants be derived? |
|---|---|---|---|
| Eddington | silent | silent | Yes, by counting |
| Ellis | An evolving block | silent | silent |
| Milgrom and McGaugh | silent | silent | silent |
| Verlinde | silent | silent | silent |
| Prigogine | The arrow comes first | Structures far from equilibrium | silent |
| Rosen | silent | Organisms no machine simulates | silent |
| Tononi | silent | Integrated information | silent |
| Friston | silent | Free energy minimized | silent |

PART SIX

# TIME, LIFE AND MIND

Part Six holds the models of time, of life and of mind: the models of Julian Barbour, Lee Smolin, Ilya Prigogine, Robert Rosen, Giulio Tononi and Karl Friston. The three models of time come first, and the models of life and of mind follow them.



Julian Barbour

# Janus and the Turn

*Julian Barbour, the Arrow of Time and Physics from Comparison*

## Abstract

The physicist Julian Barbour builds his physics on Mach's principle: motion, inertia and time itself are only relations among the things of the world. Inertia is the tendency of a body to keep its state of motion. Barbour and the physicist Bruno Bertotti showed that dynamics can be derived from comparing configurations alone. Dynamics is the part of physics that says how bodies move. A configuration is an arrangement of all the bodies of the world at one instant. Barbour argued in his book *The End of Time* (1999) that the world is a collection of instants. He argued that the world contains no time that flows. A law is symmetric in time when the law treats past and future alike, and an arrow of time is a direction from past to future. Barbour showed in his book *The Janus Point* (2020) that a law symmetric in time can still give every observer an arrow of time. Each observer has an arrow that points away from a central point of least structure, and Barbour places no special condition at a beginning. I set out physics from comparison in the books of the physics collection of the Immanent Metaphysics, called the collection for short. The Immanent Metaphysics is the philosophy that I set out in my book *An Immanent Metaphysics*. The collection agrees with Barbour more than the collection differs from him. The collection calls any interaction that yields a verdict of same or different a comparison, such as setting a ruler beside a board.

On the collection's account comparison, interaction and relation are one act under three names. The collection argues that inertia is a comparison, and the collection derives Mach's principle from a principle of its own. The principle of the collection is that a difference which no comparison can register is no difference. The collection argues that the direction of time is present in every act of comparison, so the direction of time needs no beginning of low entropy, where entropy is a count of the states of a system that cannot be told apart from one another. The collection also argues that every record is a record of the past. The collection argues too that there must be something for a comparison to be about. The collection differs from Barbour on one question: whether time is real. The collection gives two everyday words exact senses. What "exists" is laid out as structure, and what is "real" is given in an actual act of comparison. The collection argues that both what exists and what is real are needed. Barbour keeps what exists and calls what is real an illusion. Barbour drew support from the Wheeler-DeWitt equation, which contains no time. The Wheeler-DeWitt equation belongs to quantum gravity, the attempt to describe gravitation by quantum theory. The arena is the geometry of space and time within which things are found. On the collection's account, the timelessness of the Wheeler-DeWitt equation is the product of putting the arena into the quantum state. The quantum state is the complete quantum description of a system. In this chapter I set Barbour's Janus point beside the collection's turn. The Janus point is Barbour's name for the central point of least structure, and the turn is the passage from one epoch of the universe to the next, where an epoch is one era of the universe that begins with its own Big Bang. I show where Barbour's picture and the collection's picture agree, and why the collection's arrow of time runs one way through every turn. In Section VI I take up the one question on which the two accounts predict different results: whether the geometry of space carries quantum degrees of freedom of its own, that is, quantum alternatives of its own. A superposition is a quantum state that is a sum of alternatives, such as a body in two places. The question is whether the geometry can be in a superposition of two geometries that no superposition of the matter produces. Barbour's argument and the collection's argument are both valid, and the two arguments part at one

> premise. Two arguments part at a premise when one argument accepts the premise and the other argument rejects the premise. The premise in dispute is about removing absolute space: removing absolute space either makes the geometry of space one more configuration of the world, or leaves the geometry as the context in which configurations are compared.

## I. Barbour's Program

Barbour begins from the physicist and philosopher Ernst Mach. Mach held that position, rest and rotation have meaning only relative to other bodies. Mach also held that we abstract time from change itself, and that time is not a container in which change happens. Absolute space would be a space that is there on its own, as a fixed stage, whether or not any body is in the space, and absolute time would be a time that runs on its own in the same way. Barbour took Mach's view as a program for physics: to build dynamics from relations alone, so that the world consists of the relations alone and absolute space and absolute time are left out.

Barbour's first result was *best matching*, a method that he and Bertotti developed and published in 1982. In best matching, a physicist compares two configurations of a universe of bodies by shifting and turning one configuration against the other until the two configurations differ as little as possible. The difference left after the matching is the physical difference between the two configurations. Barbour builds dynamics from the physical differences that remain after best matching. General relativity is Albert Einstein's theory of gravitation, in which gravitation is the geometry of space and time. Barbour and Bertotti showed that the formal structure of general relativity fits the pattern of a dynamics built from best matching, with no background grid of space and time, provided that the thin-sandwich conjecture is true (Barbour and Bertotti 1982). The thin-sandwich conjecture is the unproved claim that two nearby geometries of space fix the whole history between the two geometries. Later, Barbour worked with the physicists Brendan Foster and Niall Ó Murchadha. Bar-

bour, Foster and Ó Murchadha derived general relativity from a starting point built, like Barbour's program, from relations alone (Barbour, Foster and Ó Murchadha 2002). The starting point was an action on the geometries of space. An action is a single quantity from which the laws of motion of a theory follow. The action has only one symmetry, one change that leaves the action unchanged: the relabeling of the points of space. Barbour's program was carried further by the physicists Henrique Gomes, Sean Gryb and Tim Koslowski, who turned the program into *shape dynamics*. Shape dynamics is a reformulation of general relativity in which only the shapes of configurations carry physical meaning, while the overall size of a configuration carries no physical meaning at all in shape dynamics.

Barbour's second result was his account of time in *The End of Time* (1999). Barbour argued that the universe is a collection of instants, and that each instant is a complete configuration of everything. He named the space of all possible configurations Platonia, after the philosopher Plato's world of eternal forms. On Barbour's account no instant flows into another instant. Barbour holds that our sense of a flowing time comes from configurations that contain what he calls time capsules. A time capsule is a structure that encodes a coherent history and so presents a past. Brains, fossils and tracks in a cloud chamber are time capsules. Barbour found support in the Wheeler-DeWitt equation, which contains no time at all. The equation is named after the physicists John Archibald Wheeler and Bryce DeWitt. The Wheeler-DeWitt equation is the central equation of the canonical quantization of general relativity. Canonical quantization is the standard method of building a quantum theory from a classical theory such as Einstein's.

Barbour's third result matters most for the arrow of time. In 2014 Barbour, Koslowski and the physicist Flavio Mercati studied many bodies moving under Newton's law of gravity. The bodies had zero total energy and zero total angular momentum, the total amount of rotation. The three physicists took the bodies as a model of a closed universe, a universe with nothing outside it. Barbour, Koslowski and Mercati found that a typical solution passes through a single point at which the configuration of the

bodies is least structured, where a solution is one possible history of the bodies. The configuration's shape grows more complex away from the point of least structure, in both directions of time. Barbour, Koslowski and Mercati call a structure that stores information about the motion a record, and records form as the complexity grows. An observer inside either half of the history sees only the records of the observer's own half, and so infers one past and one future. Barbour named the point of least structure the Janus point, after Janus, the Roman god with two faces, and he built a theory of time on the Janus point in his book *The Janus Point* (Barbour 2020; reviewed by Perkowitz 2022). In Barbour's theory the law of motion treats past and future alike, and no special condition is placed at any beginning, yet every observer has an arrow of time pointing away from the Janus point. The idea of entropy comes from the science of heat, and the idea was built for steam engines and for gases in boxes. Barbour also argues that entropy is the wrong tool for an expanding universe, which has no box around it.

Barbour has also answered Wheeler's claim that every physical thing derives from information, a claim that Wheeler summed up as "it from bit". A bit is a single unit of information, the answer to one question of yes or no. Barbour holds the reverse: things come first, and "Probabilities without things are pure nothings" (Barbour 2015).

Barbour has established three results, and the collection credits Barbour plainly with all three. First, Mach's principle can be made the foundation of a working dynamics, one that recovers general relativity. Second, a law that is symmetric in time can give every observer an arrow of time, with no special initial condition. Third, the felt past is carried by records, structures that encode a history.

## II. Where the Collection Stands With Him

### Inertia is a comparison

The collection accepts Mach's principle, and the collection gives a reason why Mach's principle is true. The usual statement of Mach's principle is that inertial frames are fixed by the distribution of mass and energy in the universe, where an inertial frame is a standard of rest and of uniform motion against which the motion of a body is measured. At the Edge of Reality, Chapter 8, one of the books of the collection, states Mach's principle in the terms of comparison: "To be at rest, to move uniformly or to rotate is always to do so relative to something. Inertia, the tendency of a body to keep its state of motion, is therefore a comparison: a state of motion is a content, and what it is measured against is its context". In the collection, content is what is found in a comparison, and context is the setting against which the content is found and measured. In physics, on the collection's account, the content is the quantum matter and the context is the geometry of general relativity. The equations of general relativity allow worlds empty of matter in which inertial frames are still fixed. So general relativity does not impose Mach's principle: in a world empty of matter, nothing is there for the frames to be compared against. The collection derives what general relativity leaves open from the principle that "a difference that no comparison can register is no difference": "frames are frames only through the comparable content that fixes them. Where content is there to compare against, there is a frame. Where nothing is, no comparison can tell one frame from another" (At the Edge of Reality, Chapter 8; the same step appears in The Gravitational Passage, Chapter 18, Section IV).

Barbour's best matching uses the principle of the collection, that a difference which no comparison can register is no difference. To match two configurations is to compare the two configurations. When Barbour matches two configurations, he removes every difference that depends only on the place of the observer or the direction the observer faces. So Barbour discards every difference that a comparison of the two configura-

tions themselves cannot register. The differences that remain after the matching are exactly the differences that a comparison of the two configurations can register. Barbour built a method from Mach's principle, and Barbour's method is a comparison of the very kind from which the collection begins.

### Time from change

Mach and Barbour hold that we abstract time from change. In the collection, a finding is an interaction that registers which of several alternatives is the case, and an instrument or an environment can make a finding with no mind needed. The collection states that "Time is the context of the order in which findings are found" (Measurement, Chapter 12, Section I). So Mach, Barbour and the collection all take time from what happens and do not treat time as a container given before the happenings. The collection also says of the order of findings: "Findings define the order of event time; they do not occur within a time given before them" (Measurement, Chapter 12, Section II). Event time is the collection's name for the order of findings, one finding after another, as Section III of this chapter describes. So the collection and Barbour both reject the picture of a time that would tick on in an empty world.

### The arrow needs no special beginning

Barbour's book *The Janus Point* (2020) has a central result: a law symmetric in time still gives an arrow of time, and the arrow comes with no special condition placed at a beginning. The collection argues for the same result on a different ground. The collection calls the direction of time that is present in every comparison the structural arrow. Axiom II is the second axiom of the Immanent Metaphysics: the directed cycle of the three roles of comparison (the immanent, the omniscient and the transcendent, which Section III describes), an order of precedence and not an order of clock time. The collection states that the structural arrow is "the structural precedence of Axiom II applied to the physical domain. The

direction of time is the direction in which comparison proceeds" (Incommensuration, Chapter 8, Section X). In every comparison there is first a stance and a range of what could be found. A stance is the side from which a comparison is made. Then comes the act in which one finding is made, and after the act comes the record of the finding. The order of stance, act and record "needs no large number of parts and no special beginning of the world: it is present in one comparison, made once" (Physics Is Not Math, Chapter 8, Section II). Essay 11 of The Basis of Physics gives a second route to the arrow of time, through the Incommensuration Theorem. The Incommensuration Theorem is a structural fact about the nature of knowing: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison, and neither can asymmetry and discontinuity. Essay 11 lists what the second route needs none of: "Perfect time-reversal is therefore precluded, and the preclusion depends on no entropy, no boundary condition, no Past Hypothesis, and no particular formalism".

The Past Hypothesis is the condition that the universe began in a state of extraordinarily low entropy. The philosopher David Albert gave the condition its name (Albert 2000). For Barbour the Past Hypothesis is unnecessary, and for the collection the Past Hypothesis is "neither an axiom nor a brute law added to physics" (The Compactification, Chapter 3, Section VIII). The structural arrow gives the direction of time without the Past Hypothesis. So the Past Hypothesis is not needed as the source of the direction of time. Read as a statement about the beginning of the universe, the Past Hypothesis splits into two parts in the collection. The first part is that the entropy of the matter at the beginning was high, as observed. The second part is that the low entropy of gravity follows from the even beginning of each epoch: each epoch begins even, with no clumping of its geometry carried from before, as Section V of this chapter describes.

### Records

An observer reads Barbour's arrow of time from records, and an observer reads the collection's arrow from records too. The collection names the observation that bears on the arrow of time: "The observation that bears on it is that every record ever found is a record of the past. No instrument holds a finding before the interaction that makes it" (Measurement, Chapter 12, Section I). The two arrows of physics are the structural arrow and the growth of entropy. The collection also says how the two arrows are joined: "A record is itself an irreversible change, a darkened grain of emulsion or a registered count, and making it raises the entropy of the instrument that holds it. So each act of recording joins the two arrows in one event" (Measurement, Chapter 12, Section VII).

### Things before information

I take Barbour's side against Wheeler in a book of the collection: Objections from Physics, Answered. The reason is that every comparison is about something: "A comparison yields a verdict, same or different: two intrinsics. The verdict is on something, in some respect that is not the thing judged: two more". The collection calls the parts that every comparison has its intrinsics: same and different are two intrinsics, and the thing judged and the respect in which the thing is judged are two more. So, in the words of the book Objections from Physics, Answered, "a comparison with nothing to be about is no comparison, and the books hold the point Barbour presses against Wheeler". The books of the collection also agree with Barbour against the digital view that his argument opposes. The digital view is the view that the world is made of bits. On the collection's account the arena is continuous and content is discrete, and the arena and content each have a character of their own.

**Entropy needs a context**

Barbour argues that entropy, an idea built for systems inside a boundary, is the wrong tool for a universe with no box around it. The collection gives the reason: "An entropy is a count: the number of states of a system that the comparisons available from some context cannot tell apart. The count is made relative to that context" (The Compactification, Chapter 3, Section V). The box around a gas is the context relative to which the states of the gas are counted. A count of states for the whole universe needs a context for the whole universe, but the universe has no context outside itself. So Barbour and the collection make one point by two separate arguments: Barbour doubts that the universe has an entropy, and the collection holds that every count has a context.

## III. What Time Is in the Collection

The collection's account of time begins from the single stance of the one who compares. In the words of the collection: "Findings are found by a comparing, and the comparing is a single stance. From one stance, any two findings stand in one relation of order: one is earlier and the other later. So time has one dimension" (Measurement, Chapter 12, Section I). The order of findings has a direction, and the direction is the order of the second axiom, Axiom II: the range of what could be found comes first, then the act, then the record, and the record shapes the next range.

Physics uses the word "time" for three objects, and the collection holds the three objects as one triple (Measurement, Chapter 12, Section III). *Geometric time* is time laid out as one structure: the proper time along paths and the order of cause carried by the metric, where proper time is the time that a clock measures along its own path. The metric is the quantity that fixes distances and durations in space and time. *Event time* is the order of findings: a discrete sequence of outcomes, each the label of one registered result. *Evolution time* is the parameter of the smooth evolution of a quantum state over the range of what could be found, where a paramet-

er is a number that marks the stages of a smooth change. Comparison has three roles, which the collection calls the *modalities*: the immanent (held in the act itself, now), the omniscient (held as structure laid out, every case in view at once) and the transcendent (implicit, held in the stance from which an act proceeds). When the modalities are applied to time, geometric time takes the omniscient role. Event time takes the immanent role, and evolution time takes the transcendent role. The three times are distinct, inseparable and not interchangeable, as the third axiom of the Immanent Metaphysics requires of the three modalities, and each of the three times needs the other two. A finding needs a quantum state whose range of possibilities the finding selects among, and a finding also needs a place in the order of cause where the record of the finding lies. Geometric time is known only through findings. Evolution time needs a preparation, which is a finding. Evolution time also needs a clock by which the parameter of evolution time is read.

The rest of the collection's account of time depends on two everyday words, "exist" and "real". The collection gives each word an exact sense: "To say that something exists is to say that it stands as structure: timeless, the same in every instance, like the pattern of a law, or the state of a system at an instant. To say that something is real is to say that it is given in an actual act of comparison: temporal, occurring now, with the future still open to possibilities not yet settled. A law exists; a measurement is real" (Comparison; The Necessary Basis, Chapter 10, Section II). In the collection's senses of the two words, geometric time exists and event time is real. The Incommensuration Theorem is the ground of the collection's whole account of time: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison, and neither can asymmetry and discontinuity. The Incommensuration Theorem forbids symmetry and continuity perfected together. Faithful reversal of a process is the running of the process backward step for step. Faithful reversal would need exactly the pairing of perfect symmetry with perfect continuity: the law of the process perfected in symmetry, and the state of the process given without a gap. So time has a direction that no law of

motion can undo, whatever symmetry the law of motion has. The Incommensuration Theorem is a structural fact about the nature of knowing. The first axiom of the Immanent Metaphysics holds that the immanent is more fundamental than the omniscient and the transcendent, and that the omniscient and the transcendent are conjugate to one another. I formulated the first axiom in or before 1991 and the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996, and I did most of my work in physics in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the Incommensuration Theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1.

## IV. Where the Roads Part: Is Time Real?

Barbour's instants are configurations: each instant is complete, and no instant flows into the next. In the collection's terms, a configuration is a state of a system at an instant, and the state of a system at an instant is the very example of what exists that the book Comparison; The Necessary Basis gives: structure, timeless and laid out. Platonia is the space of all configurations, and Platonia is the omniscient: everything laid out at once, every case in view. Barbour keeps what exists, and he holds that the real act given now is an illusion of the mind.

The collection keeps both what exists and what is real, because each needs the other. A configuration is known as a configuration only through findings. Every measured position is a comparison of a body with a standard, and every measured position leaves a record. Barbour holds that a time capsule is a structure within one instant, made by no earlier act. The collection holds that a record is the result of the act that the record records. On the collection's account a record is a finding laid out by an act. Barbour denies the collection's premise that a record is the result of the act that the record records. On the collection's premise, the instants that Barbour keeps are themselves laid out from acts of comparison, and removing the acts would remove the means by which any instant is known.

The block universe is the view that past, present and future are equally real and laid out once. The Basis of Physics, Essay 11 says of the block universe: "The block universe takes geometric time for the whole, and drops event time". Barbour's Platonia drops event time in the same way as the block universe does, and Platonia also drops the third member of the triple, evolution time, whose range of what could be found is what each act selects from.

Barbour drew support for timelessness from the Wheeler-DeWitt equation, which contains no time. The collection says exactly where the timelessness of the Wheeler-DeWitt equation comes from, in a passage of The Unquantized Arena, Chapter 6, Section VI: "The equation contains no time parameter. The quantum state, which in every other quantum theory evolves in the time of an arena, has nothing in which to evolve. That is the problem of time (Isham 1993). I read it as the category error in its plainest form. The context in which things happen has been put into the quantum state, instead of serving as the arena in which the state evolves". The citation Isham 1993 is the physicist Chris Isham's review of the problem of time in canonical quantum gravity. In the passage, the category error is the mistake of putting the context in which things happen into the quantum state, as if the context were one more thing that happens. The timelessness of the Wheeler-DeWitt equation is therefore a feature of a description in which the arena of physics has been quantized, and the collection holds that gravitation is not quantized. Barbour took a property of a description that quantizes the arena for a discovery about the world. Section IX of Essay 12 of The Basis of Physics states what the problem of time is in terms of the three times. The time of general relativity is geometric time, and the time of quantum mechanics is the parameter of evolution. The two conjugate times are geometric time and evolution time. Geometric time and evolution time hold the omniscient and the transcendent roles, and the first axiom of the Immanent Metaphysics makes the omniscient and the transcendent conjugate, that is, paired with each other. Essay 12 states: "The problem of time is what one gets by asking the two

conjugate times to be one time without going through the third", and the third time is the time of the act of measurement, where geometric time and evolution time come together.

The collection answers Barbour's time capsules with the same distinction, between what exists and what is real. For Barbour, a time capsule encodes a history without being the result of a chain of causes running back through earlier instants. The collection holds that "Causation is established, and determinism never" (Measurement, Chapter 12, Section IV). A causal connection is a connection without a break along the order of findings. Hence a causal connection pairs continuity and asymmetry, which is one of the two pairings that the Incommensuration Theorem allows, and the other pairing allowed by the Incommensuration Theorem is discontinuity and symmetry. Every record ever found is a record of the past because a record is the result of the act that the record records.

## V. The Janus Point and the Turn

The collection's *turn* is the passage from the end of one epoch of the universe to the beginning of the next epoch. I set out the collection's cosmology, its account of the universe as a whole, in *The Compactification* and *At the Edge of Reality*. In the collection's cosmology, space has six further dimensions besides its three, held compact and too small to see, and the end of every black-hole interior is the start of a new epoch of the universe. A black-hole interior is the inside of a black hole. The six further dimensions are held compact: each of the six is kept curled up, at the same size and shape at every point. At the end of every black-hole interior, the conditions fail that hold the six further dimensions compact, and the ten-dimensional geometry restores a context. The collection identifies the restoration of a context with the Big Bang of the next epoch. No comparison registers the turn as an event, and the cycle of epochs has no first turn (The Compactification, Chapter 1, Section V). The Janus point and the turn have the same place in Barbour's account and in the collection's account:

each is where an arrow of time starts, and each is a state of least structure from which structure grows. Barbour's Janus point is the configuration of least complexity. The collection's new epoch begins even, with no clumping of its geometry carried from before, apart from the small departures from evenness that the Incommensuration Theorem requires (The Compactification, Chapter 3, Section VI). In both accounts the low order of the beginning follows from what the beginning is. No physicist adds the low order by hand as a condition.

Mach's principle appears in both accounts, and in the collection Mach's principle determines what happens to time at the turn. I describe what happens at the end of a black-hole interior in At the Edge of Reality, Chapter 13: "there is no comparable distribution of mass and energy against which a standard of rest could be defined. The Mach principle then fixes no frame. Time goes with it". The large-scale direction of time is what goes at the end of the interior: the direction set by the growth of entropy, by the expansion of the universe and by the reference of distant matter, which is the standard of rest. The order inside each act of comparison remains in place: "The one-way order inside each act of comparison, from the stance through the finding to what is laid out (Chapter 4), is not reversed; at the end of an interior there is no content that can be compared with, and so nothing for that order to arrange". Barbour's universe and the collection's turn both follow Mach's principle on one point: where nothing is left to compare against, no frame is fixed, and the large-scale measure of time has nothing to rest on.

The Janus point and the turn differ in three ways. The first difference is where the starting point of the arrow lies. Barbour's Janus point is a point within one solution of one law, a configuration through which the history passes. The collection's turn lies outside every history: no comparison made in the old epoch registers the turn, and the new epoch's context reforms with no prior identity, which means that the new context carries over no identity from before the turn. The second difference is how many ways the arrow points. Barbour's arrow runs away from the Janus point in both directions. On the far side of the Janus point, observers have their

past toward the same point as our past. No observer can tell the two pictures apart by a finding, because no observer has a record from the far side of either the Janus point or the turn (Appendix B, "The Janus point and the turn"). The two pictures differ in what the arrow is, and the third difference sets out what the arrow is in each picture. The arrow of the collection runs one way through every turn, because the arrow is the order of the second axiom, renewed in every act of comparison in every epoch, and the arrow is inherited from no point. The cycle of epochs runs in one sequence. Each epoch's large-scale arrow points away from the epoch's own turn toward the epoch's own end. The third difference is where the arrow comes from. Barbour's arrow is a property of typical solutions of a particular dynamics, the gravitational problem of many bodies. An observer infers Barbour's arrow from records. The collection's arrow is present in a single comparison and needs no dynamics, no large number of parts and no particular solution.

Barbour explains why an observer infers one direction, and Barbour's explanation uses the collection's arrow. Barbour's observers infer a past from records, and a record is by its nature later than what the record records, because a record is a finding laid out by an act. The direction from act to record is the order of the second axiom. So Barbour's observers read the structural arrow from their records. Barbour's dynamical arrow is the growth of complexity away from the Janus point. The dynamical arrow belongs with the collection's second arrow, the growth of entropy, because Barbour's dynamical arrow and the growth of entropy are both found in systems of very many parts. Both arrows need a state of least structure to grow from. The collection keeps both arrows and says how the two arrows are joined: in every act of recording. Barbour found the dynamical arrow, and he read the dynamical arrow through the structural arrow without naming the structural arrow.

## VI. Where the Predictions Part, and Why

Most of what divides Barbour from the collection is a difference of kind, a difference in what a thing is, and Section IV set out the difference of kind: whether time is real. Only one difference is a difference of prediction, a difference in what a measurement will find. The register dated 4 November 2026 sets Barbour's predictions beside the collection's predictions, and the register lists no other difference of prediction. The register is Appendix B of this volume, a record of its own, dated three days after the sealed record of 1 November 2026. The sealed record is the register of the collection's predictions whose wording I fixed on its date and do not revise. Appendix B quotes each prediction from the sealed record. I set the argument of the book on which the sealed prediction rests beside Barbour's own reasoning. I then find the step at which the two arguments part.

### Whether the geometry of space carries quantum degrees of freedom of its own

**The sealed prediction.** "No effect will show the geometry carrying quantum degrees of freedom of its own, beyond those tied to the alternatives of the matter. A description of the small waves of the geometry by quanta holds below the Planck curvature, and its quanta are quanta of that description, never quanta of the arena". I registered the sealed prediction on 1 November 2026 as Prediction 3 of *The Registered Predictions of Physics from Comparison*, and the sealed record names The Unquantized Arena as the book in which the prediction is argued. The small waves of the geometry are ripples in the geometry of space and time, such as the gravitational waves that observatories detect. The Planck curvature is the curvature whose radius is the Planck length, the scale at which an object's gravitational size equals its quantum size, and the Planck curvature is not a least length.

**The argument of the book.** I set out the argument step by step in The Unquantized Arena, Chapter 6, Section II and then state the argument in seven sentences. The argument begins from the Incommensuration Theorem: "any comparison perfected at its foundation is either continuously asymmetric or discontinuously symmetric". The argument uses two laws: "Content is governed by symmetry and context by continuity". The argument makes one identification, a claim about what a thing is: gravity is the context of physics. In *The Unquantized Arena* I number the identification P18 and check the identification against four markers in Chapter 5: "the matter and forces of particle physics are content, and gravity is the context of physics, its arena". In the book, quantization is the passage of a description of content from one of its two forms to the other. In *The Unquantized Arena* I call the passage the mode exchange. Proposition 6.1 of the book states that the arena admits no mode exchange. Proposition 6.1 has a second strand, one of its independent lines of support, about the part that the arena plays: "The mode exchange of a content is a passage between two descriptions of that content, and the two descriptions are compared within one arena that stays as it is", and "A mode exchange of the arena would need a further setting in which its two descriptions could be compared, and that further setting would then be the context of physics in the arena's place". Proposition 6.3 then fixes what "not quantized" means, and the second part of Proposition 6.3 is the ground of the prediction: "(ii) Nothing is a quantum of the arena itself, at any scale". I took the words "beyond those tied to the alternatives of the matter" in the prediction from Chapter 7 of the book, in which each alternative of the matter has its own classical geometry. Section VII of Chapter 7 says of the free waves of the geometry: "I reason that the free curvature of the arena, the Weyl part of Section III, belongs to the context of the content that produced it, and carries that content's alternatives". So on the book's account every superposition that the geometry shows is the superposition of the matter whose context the geometry is, and the geometry has no alternatives of its own.

**Barbour's argument.** Barbour begins from Mach, as Section I set out: only the relative configurations of the universe are physical, with nothing behind the relative configurations. For a universe governed by Einstein's theory, the configurations are configurations of the matter and of the geometry of space together. Best matching applies to the geometry as best matching applies to the matter: Barbour compares two geometries of space by shifting the one against the other until their difference is least (Barbour and Bertotti 1982), and in shape dynamics changes of scale are allowed in the matching as well (Gomes, Gryb and Koslowski 2011). Barbour then applies quantum theory to the universe as a whole. Barbour's paper "The timelessness of quantum gravity: II. The appearance of dynamics in static configurations" has an abstract that begins: "A strategy for quantization of general relativity is considered" (Barbour 1994). In Barbour's quantum theory the state of the universe is a wave function on Platonia, the space of all configurations of the universe. The wave function obeys an equation of the same kind as the Wheeler-DeWitt equation. A wave function is a quantum state written as an amplitude for each configuration. An amplitude is the number that the quantum state gives to one possible outcome. Barbour's instants "are not embedded in any kind of external or internal time" (Barbour 1994). Each step of Barbour's argument follows from the step before. In Barbour's account the geometry of space is one part of the configuration, and the configuration is the variable of a quantum state. So in Barbour's account the geometry of space carries amplitudes of its own, as every variable of a quantum state does, including amplitudes for geometries that no superposition of the matter produces.

**Where they part.** Barbour and the collection both start from Mach, and the two part over what Mach's principle removes. For the collection, removing absolute space makes the frame depend on the content that fixes the frame, and leaves the geometry as the context in which every configuration of the content is compared and laid out. Section II quoted the collection on the frame: "frames are frames only through the comparable content that fixes them". For Barbour, removing absolute space

makes the geometry of space one more part of the configuration of the universe, of the same kind as the matter, compared with other configurations by best matching.

**Whose step, and what decides it.** Both arguments are valid: in each argument every step follows from the premises before the step, and the two arguments differ in one premise. The premise in dispute can be stated in one sentence: when absolute space is removed, the geometry of space is one more configuration of the universe, and not the context in which the configurations of the universe are compared. Barbour affirms the premise in dispute, and The Unquantized Arena denies the premise by identifying gravity as the context of physics (P18). The premise in dispute is a premise about what a thing is, an identification, and no derivation inside either account settles the premise.

In Barbour's own construction a reader can see where the context goes once the premise is affirmed. In best matching, Barbour compares two configurations under a measure of difference defined on the space of configurations, and a history is a path in the space of configurations (Barbour and Bertotti 1982; Barbour, Koslowski and Mercati 2014). Once the geometry of space is a configuration, Platonia and its measure of difference are the setting in which every configuration is compared. The geometry is one of the configurations compared in Platonia. By the second strand of Proposition 6.1, a quantum arena would need a further setting, and Platonia with its measure of difference is then that further setting. Platonia is the context of physics in the arena's place. The Unquantized Arena states the consequence for the canonical equation, the Wheeler-DeWitt equation: once the arena is itself the state, "the formalism has no context left, and its evolution has no parameter" (The Unquantized Arena, Chapter 6, Section VI). Barbour draws the same consequence and reads the consequence as a discovery, that there is no time, and Section IV took up Barbour's reading. So Barbour and the collection each carry their own premise through to the consequence that the other side foresees. No step of either account contradicts a step of the other account.

Barbour and the collection read Mach's principle differently, and the two readings also differ in what a measurement could find. On the account of The Unquantized Arena the matter carries every superposition of geometries, since the geometry has no alternatives of its own. On Barbour's account the wave function of the universe can hold a superposition of geometries that no superposition of the matter produces, because the geometry of space has amplitudes of its own. The Unquantized Arena, Chapter 19, Section III, names two kinds of observation that decide between the two accounts: "the cross-section for the scattering of small waves of the geometry, computed in their description by quanta, at energies where the corrections of the effective theory are large", and "every search for an effect in which the geometry carries quantum degrees of freedom of its own, for example a superposition of macroscopically different geometries that no superposition of the matter sources and that is not a state of free small waves in their description by quanta". A cross-section is a measure of how often a scattering happens, and the effective theory is the effective field theory of gravity, which describes the small waves of the geometry by quanta. In the sealed record I name no coming measurement of either kind, and I state that "Below the Planck curvature the account and the effective field theory of gravity give the same result for every experiment now proposed". Two masses are entangled when the quantum states of the two masses are linked, and neither mass can then be described on its own. The entanglement of two masses through gravitation leaves the two accounts undecided, since the collection predicts the entanglement and a quantized geometry "gives the same phase", in the sealed record's words.

Each side can learn from setting the two accounts side by side. For the collection, Barbour's program is a worked case of Proposition 6.1. A relational program is a research program in which physicists build physics from relations alone. Even a careful relational program still has a context when the program puts the geometry into the quantum state, because the program moves the context into the space of configurations and loses time in the space of configurations, as The Unquantized Arena foresees. For

Barbour, the collection shows that a relational starting point is consistent with a geometry that is not quantized: the collection follows Mach's principle about the frame, and in the collection the geometry stays the context, with no alternatives of its own. On the geometry, the collection carries Mach's principle further than Barbour does, because in the collection every superposition of the geometry of space is a superposition that the matter gives to the geometry. On time, Barbour carries Mach's principle further than the collection does, since Barbour removes time along with absolute space.

## VII. Summary

Barbour and the collection agree on more points than either agrees on with the usual account of time in physics. Inertia is a comparison, and a frame is a frame only through content that is there to compare against. Time is taken from what happens, and time is not a container given before the happenings. The arrow of time is present with no special condition placed at a beginning, and the Past Hypothesis is not a law of nature. Every record is a record of the past. A comparison must be about something. And entropy, which is a count, needs a context that the universe as a whole does not have.

Barbour and the collection part on whether time is real. Barbour keeps the instants, what exists laid out as structure, and calls the flow of time an illusion. The collection holds time as a triple of geometric time, event time and evolution time. The collection also holds that what exists and what is real each need the other: every instant is known through acts of comparison, and the act that is given now is real. Barbour drew on the timeless Wheeler-DeWitt equation, which is the product of quantizing the arena. The collection holds that the arena is not quantized. The Janus point and the turn are each the start of an arrow in a state of least structure, and at both the Janus point and the turn Mach's principle fixes no frame. The Janus point lies within one history, and Barbour's arrow runs both ways

from the Janus point, while no comparison registers the turn. The collection's arrow runs one way through every epoch, because the arrow is renewed in every act of comparison.

The one difference of prediction is whether the geometry of space carries quantum degrees of freedom of its own. Barbour's argument is valid, the argument of The Unquantized Arena is valid, and the two arguments part at one premise. For Barbour, removing absolute space makes the geometry one more configuration of the universe. For the collection, removing absolute space leaves the geometry as the context in which configurations are compared. When Barbour's program is carried through, the program moves the context into the space of configurations and loses time in the space of configurations, and The Unquantized Arena foresees the loss of time for a quantized arena. One kind of observation would decide between the two accounts: an observation of a superposition of geometries that the matter does not carry. Barbour removes time along with absolute space, while the physicist Lee Smolin, whose model is the subject of the next chapter, holds that time is real and fundamental, and that the laws of physics themselves change within time.

**Key Concepts**

- In best matching, Barbour compares two configurations and counts as a difference only what a comparison of the two configurations can register. In the collection, Mach's principle follows from the principle that a difference which no comparison can register is no difference.
- Time is the context of the order in which findings are found, and time is not a container given before the findings.
- The structural arrow is the order of the second axiom, present in a single comparison, and the structural arrow needs no Past Hypothesis.
- Geometric time exists, event time is real, and evolution time carries the range of what could be found. The three times are one triple.
- The timelessness of the Wheeler-DeWitt equation comes from putting the arena into the quantum state.
- Barbour's records presuppose the structural arrow, and Barbour's growth of complexity belongs with the second arrow, the statistical arrow of the growth of entropy.
- The Janus point and the turn each start an arrow of time in a state of least structure. No comparison registers the turn, and the collection's arrow runs one way through the turn.
- Barbour and the collection disagree about one premise in prediction: whether the geometry of space is one more configuration of the universe, or is the context in which configurations are compared. A program that affirms the first answer moves the context into Platonia and loses time in Platonia.

## Terms

**Best matching.** Barbour and Bertotti's method of comparing two configurations by shifting and turning one against the other until their difference is least, and building dynamics from what remains.

**Event time.** The order of findings: a discrete sequence of registered outcomes.

**Evolution time.** The parameter of the smooth evolution of a quantum state over the range of what could be found.

**Exist and real.** To exist is to stand as structure, timeless and laid out; to be real is to be given in an actual act of comparison, now.

**Geometric time.** Time laid out as one structure: proper time and the order of cause carried by the metric.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Janus point.** In Barbour's account, the point of least complexity in a typical solution of the gravitational problem of many bodies, from which complexity grows in both directions.

**Mach's principle.** Inertial frames are fixed by the distribution of mass and energy in the universe.

**Modalities.** The three roles of comparison: the immanent (held in the act itself, now), the omniscient (held as structure laid out, every case in view at once) and the transcendent (implicit, held in the stance from which an act proceeds).

**Mode exchange.** In The Unquantized Arena, the passage of a description of content between its two forms; quantization is the mode exchange, and The Unquantized Arena holds that the arena admits none.

**Past Hypothesis.** The condition that the universe began in a state of extraordinarily low entropy.

**Platonia.** Barbour's name for the space of all possible configurations of the universe, after Plato's world of eternal forms.

**Structural arrow.** The direction of time as the direction in which comparison proceeds: from the range of what could be found, to the act, to the record.

**Turn.** The passage from the end of one epoch of the universe to the beginning of the next, at the end of every black-hole interior; no comparison registers the turn as an event.

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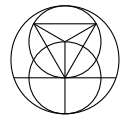

Lee Smolin

# Time Is Real

*Lee Smolin and Physics from Comparison*

## Abstract

If time is real, must the laws of physics change? Lee Smolin is a theoretical physicist, and he has argued for forty years that time is real. He has also argued that the universe is one and has a history, that the laws of physics are not a timeless mathematical object standing outside the world, and that physics must be built from relations. The physics collection of the Immanent Metaphysics is the set of books in which I set out physics from comparison. I call the physics collection the collection for short. The collection holds each of Smolin's four claims, on grounds of its own. The collection also shares two of Smolin's specific moves. The first of the two shared moves is a principle by which two things are one thing when no comparison registers a difference between the two things. In the principle, every interaction of any kind counts as a comparison. An epoch is a stage of the history of the universe. The second shared move is a new epoch of the universe that begins where the interiors of black holes end.

Smolin and the collection differ on what keeps time real, and so they answer the opening question differently. A future is open when the present does not already contain it. Smolin keeps the future open by letting the laws themselves change, and by letting the constants of each new universe vary from the constants of its parent, the universe it came from. The collection keeps the future open with laws that stay the same. The

ground is the Incommensuration Theorem, a structural fact about the nature of knowing: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison. The Incommensuration Theorem forbids any law to be perfected together with continuity. Determinism is the claim that the laws and the present fix the future in full, and determinism needs a law perfected together with continuity. So determinism cannot be had. In the collection the axioms of the Immanent Metaphysics fix the structure of physics, its forces, its kinds of particle and its dimensions, in every epoch. The epochs form a single sequence, and no epoch inherits anything from a parent.

Smolin and the collection also differ on gravity and on quantum theory. Smolin helped found loop quantum gravity, a theory in which areas and volumes come in discrete steps. The arena of physics is the geometry of space and time within which everything is found, and the collection holds that the arena is continuous, with no least step, and is not quantized (not made of quantum units). Smolin seeks a realist completion of quantum mechanics: a deeper theory that describes what is there whether or not anyone observes it. The collection derives quantum mechanics and finds quantum mechanics complete in its scope. In this chapter I first set out Smolin's program at full strength. Then I set out what the collection shares with Smolin's program, and where and why the two accounts part. The registered predictions are the sealed record of the collection's predictions. In four places the registered predictions and Smolin's work say that experiment will find different things. For each of the four places, the chapter sets the argument of the collection's book beside Smolin's own argument, and finds the premise or step at which the two arguments part.

## I. A Physicist Who Says Time Is Real

Lee Smolin works at the Perimeter Institute for Theoretical Physics. He is one of the founders of loop quantum gravity, a research program that treats the geometry of space by the methods of quantum theory. In 1995

Smolin and the physicist Carlo Rovelli made a computation in loop quantum gravity, and they found that the area of every surface and the volume of every region take separate, discrete values. In 1992 Smolin proposed that each black hole gives rise to a new universe, whose constants of nature differ slightly from the constants of its parent, the universe in which the black hole formed. Each black hole gives rise to one more universe, so over many generations the universes that make many black holes come to predominate. Smolin called the proposal *cosmological natural selection*, and he set it out at length in his book *The Life of the Cosmos* (1997). String theory is the program in which the smallest parts of matter are tiny vibrating strings. In *The Trouble with Physics* (2006) Smolin argued that string theory had taken over the field without producing a test.

Since *Time Reborn* (2013), Smolin's central claim has been about time. Smolin holds that time is real and fundamental, and he holds that the picture of the universe as a timeless block, in which past, present and future are equally real, is wrong. In 2014 Smolin wrote *The Singular Universe and the Reality of Time* with the philosopher Roberto Mangabeira Unger. In that book Smolin adds that there is one universe, and only one, and that the laws of nature can change. Smolin argues that the usual method of physics fails when a physicist stretches the method to the whole universe. The method states timeless laws for a small system set in a larger world. Then the physicist supplies the starting conditions of the small system. For the whole universe the method fails, because nothing lies outside the whole universe to supply its starting conditions or to serve as its clock.

Smolin and the physicist Marina Cortês have built models in which the universe is a process of unique events. In those models each event differs from every other event in its relations. The causal past of an event is every earlier event that could have influenced it. Cortês and Smolin require that "any two events must have non-isomorphic causal pasts": no two events have causal pasts of the same shape. The requirement is a form of Leibniz's principle. The philosopher Gottfried Wilhelm Leibniz held that things alike in every respect are the same thing. In 2012 Smolin proposed a *principle of precedence*: that "the outcome of a measurement on a quantum sys-

tem is selected randomly from the ensemble of outcomes of previous instances of the same measurement on the same quantum system". Smolin pictures the laws of quantum physics, on the principle of precedence, as habits that nature has formed. A situation with no precedent is free to produce something new. In *Einstein's Unfinished Revolution* (2019) Smolin argues that quantum mechanics is incomplete. He argues that a realist completion of quantum mechanics is still to be found: a theory that describes what is there whether or not anyone observes it.

Across his work Smolin makes one sustained argument: physics went wrong when physicists took their timeless mathematics for the world. The collection draws the same conclusion about timeless mathematics, and Section II sets out how much more of Smolin's work the collection shares.

## II. What the Collection Shares

### Time runs one way in every act

The collection finds the direction of time in the structure of comparison itself. In the collection every interaction is a comparison, whether a person, an instrument or an environment makes it, and no mind is needed. The claim is stated in the collection's book Incommensuration, Chapter 8, Section X: "The non-entropic arrow of time is the structural precedence of Axiom II applied to the physical domain. The direction of time is the direction in which comparison proceeds". Axiom II is the second axiom of the Immanent Metaphysics. Axiom II sets the parts of every comparison in one order, an order of precedence and not of clock time. Entropy is the measure of disorder in a system of many parts. A non-entropic arrow is a direction of time that does not come from entropy.

Every comparison proceeds in one order. First comes the stance, together with everything that might be found. The stance is the side from which a comparison is made, and it belongs to every comparison, human or not. Then comes the act of comparison, and then the record, which,

once made, will always have been made. The record, once laid down, shapes the next stance (Home in the World, Records That Are Never Unlaid). The collection calls the one-way order of every comparison, from stance to act to record, the structural arrow of time. The structural arrow is present in every single comparison, and it needs no beginning of the universe in a state of low entropy. The entropic arrow is the growth of entropy in systems of many parts. The entropic arrow is real too. Making a record raises the entropy of the instrument that holds the record, so the entropic arrow points the same way as the structural arrow (Why Time Travel Is Not a Concept). A finding is an interaction that registers which of several alternatives is the case. So on the collection's account time is real because comparison runs one way, and every finding of physics is a comparison.

On the collection's account the universe is likewise a process, and not a static container. The Last Turtle, Chapter 5, Section VII, calls the universe "a process whose structure is the precondition for the emergence of beings who can ask what the universe is". In the same section The Last Turtle holds that creation "has no time and no source; it is an aspect of every event". Smolin's universe of unique events, each event made new, and the collection's universe as a process, with creation an aspect of every event, are the same picture drawn from two sides. In both pictures the universe is a process, and something new comes to be in every event.

**No view from outside**

Smolin objects to stretching the method of physics to the whole universe, and his objection is an objection to the view from outside, a description of the universe made from a place outside the universe. The collection makes the same objection. Every comparison has two sides: the side from which the comparison is made, and the side about which it is made. The two sides are inseparable, so every description is made from somewhere (Physics Is Not Math, Chapter 3, Section II). The view that seems to stand nowhere is the objective standpoint taken to its limit, and it is often called

the view from nowhere. Physics Is Not Math says that the view from nowhere "is real, and it is one of the great achievements of knowing. The laws of physics are stated in it" (Chapter 3, Section VI). The error is to take the view from nowhere for everything. Chapter 3 of Physics Is Not Math calls the error taking the frame of mathematics for everything (Section VIII).

The collection puts four fields in order by what each field presupposes. The collection calls the order the order of depth: metaphysics first, then physics, then computation, and mathematics last. Mathematics comes last for three reasons. A run checks every proof, and a run is a computation carried out step by step. Every run is a physical process, and every finding of physics is a comparison made from inside the world (Physics Is Not Math, Chapter 5). Smolin rejects the picture of the universe as a timeless mathematical object, and the collection rejects the same picture. The collection also gives a ground for the rejection: the order of depth, the order of what each field presupposes.

**Relations first, and the identity of what cannot be told apart**

Smolin is a relationalist: he holds that a thing is what its relations make it. The collection starts from relation itself. The collection's one premise, the Root Tautology, is that comparison, interaction and relation are one act under three names. The Last Turtle, Chapter 1, Section VI, treats the relationship as "more fundamental than either of the two things related".

Smolin and the collection also share Leibniz's principle, and each states the principle in a precise form. Cortês and Smolin distinguish every event from every other event by the causal past of the event. The collection states its principle as "a difference that no comparison can register is no difference". The collection also states the principle exactly. Take two things, and compare each of them with any thing whatever, by any possible comparison. When comparing the first and comparing the second always have the same verdict, the two things are one (At the Edge of Reality, Chapter 11). Two identical coins, one in each hand, are two coins.

Compare each coin with your left hand: one coin is in your left hand, and the other coin is not. By the same principle the collection joins the ends of all black-hole interiors into one end. The interiors themselves stay distinct, and Section V gives the reason. Smolin uses Leibniz's principle to make every event unique. The collection also states Leibniz's principle as a fact about comparison, and uses that statement to say exactly which things are one.

**One universe, and its beginning inside a black hole**

Smolin and Unger argue for one universe and against a population of universes that no one could observe. On the collection's account the universe is one sequence of epochs, each epoch following the last and beginning with a Big Bang of its own. The book At the Edge of Reality speaks of "a single sequence of epochs, and a structure fixed in every epoch by the axioms" (At the Edge of Reality, Notes to Chapter 20). The collection also shares the identification Smolin made in 1992: the interior of a black hole is the origin of a universe. The Gravitational Companion names Smolin among the authors whose proposals the Companion shares. The Gravitational Passage, Chapter 18, Section XII, cites Smolin as a precedent.

On the collection's account space has six compact internal dimensions beside its three large directions. Compact dimensions are closed on themselves and of finite size. The six internal dimensions are a complex projective plane and a sphere, and the collection also calls them the six dimensions of possibility. At the end of every black-hole interior, the six internal dimensions lose the conditions that hold them compact. The ten-dimensional geometry then restores a context. One of the ten dimensions is time, three are the large directions of space, and six are the internal dimensions. In the collection's terms, content is what is found in a comparison, and context is the arena in which the content is found. In physics, content is quantum matter, and context is the geometry of general relativity. The col-

lection identifies the restored context with the Big Bang of the next epoch, and calls the passage from the end of the interior to the next epoch the *turn* (The Compactification, Chapter 1, Section V).

### The string theory critique

Smolin argued in 2006 that string theory had not earned its place in physics, because it had produced no test. The collection agrees that string theory is the wrong route. String theory needs ten dimensions of space and time, and the collection obtains ten dimensions without strings: one of time, three of space and six of possibility, each count found from the structure of comparison (Measurement, Chapter 4).

## III. Two Kinds of Precedence

Smolin's principle of precedence and the collection's second axiom share a word, precedence, and they share much of what the word means. In both, what has happened shapes what can happen next, and the order cannot be reversed. The Last Turtle, Chapter 3, Section VI, states the order of the second axiom: "The order Axiom II states is one of precedence, not of clock time". The order runs from many to one, three times over: "Many existing patterns converge into one creative act. Many creative potentials converge into one actual event. Many actual events converge into one knowable structure".

The two kinds of precedence differ in where the precedence is held, that is, in what carries the past into the present. Smolin's precedence is a memory of instances. On Smolin's principle, nature draws the outcome of a measurement from the outcomes of earlier measurements of the same kind, and a law is the habit that the earlier outcomes have formed. So Smolin must say how nature has access to its own past instances, and what counts as the same measurement. The collection's precedence is the structure of each single comparison. Every comparison proceeds from a stance that already contains what earlier comparisons have laid down,

and the record of the comparison becomes part of the stance from which the next comparison proceeds. So on the collection's account nature consults no ensemble, no whole set, of earlier instances, and nature needs none. The past shapes the present by being part of what each act starts from, and not by being looked up.

On the collection's account a law is a finding, and not a habit. In Measurement, Chapter 2, Section V, the collection says: "A law of physics states what stays the same when the circumstances of a measurement change". In the collection's terms a law states a sameness of content across a difference of context, and such a sameness is a symmetry. With his principle Smolin aims at a world in which the past constrains the present without a timeless rulebook standing outside the world. The collection has such a world in the order of every act of comparison.

## IV. Laws That Stay the Same, and a Future That Stays Open

The deepest difference between Smolin and the collection concerns the laws of physics. Smolin lets the laws change because he sees no other way to keep time real. If the laws are timeless and fix every state from the state before it, then the future is already contained in the present. Time then adds nothing. The collection keeps what Smolin fears to lose, a future not contained in the present. And the collection keeps that future with laws that stay the same.

The ground of the collection's claim is the Incommensuration Theorem: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The Incommensuration Theorem is a structural fact about the nature of knowing. I formulated the first axiom of the Immanent Metaphysics in or before 1991. I formulated the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996. I did most

of my physics work in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the Incommensuration Theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1.

A law is symmetry: the same rule, everywhere and at every time. Determinism is the claim that the laws and the present state fix every later state. Determinism needs the symmetry of a law made perfect, and at the same time it needs every state specified at every point with no gap, which is continuity made perfect. Causality Without Determinism, Chapter 1, Section VIII, quotes Incommensuration on the point. Determinism "is an assertion of total symmetry and total continuity", and "since symmetry and continuity cannot both be perfected, total specification (continuity) of lawful structure (symmetry) is structurally precluded". So a law can hold everywhere and always, and still the present does not contain the future. Causes are real, and determinism cannot be had. Superdeterminism is a deterministic completion of quantum mechanics in which the settings of an experiment are fixed together with the states of what is measured. The Incommensuration Theorem excludes superdeterminism along with determinism (Causality Without Determinism, Chapter 3, Section VIII). Smolin protects an open future by letting the laws evolve. The Incommensuration Theorem already secures an open future, with no change in the laws.

The collection says plainly what the axioms fix, and what they leave to measurement. The axioms fix structure. The axioms fix the gauge group of the forces, the symmetry that sets which forces there are (The Kinds of Particle, Chapter 4). The axioms also fix the kinds of particle and their charges, the three generations of matter particles, and the dimensions of time, space and possibility. The axioms fix the same structure in every epoch. The axioms do not fix sizes: "The axioms are structural and carry no units, so they fix roles and not sizes". What experiment finds are dimensionless ratios (Measurement, Chapter 7, Section VIII). The ratio of two masses is one dimensionless ratio, and a dimensionless ratio comes out the same in every system of units. The Standard Model is the established theory of the particles and of every force but gravitation. The col-

lection gives every one of the twenty-six numbers of the Standard Model a stated standing: the collection says of each number whether it is derived or measured (The Spectral Chain, Chapter 1, Section VII).

## V. Cosmological Natural Selection and the Turn

Cosmological natural selection and the turn begin from the same identification: a universe is born at the end of a black hole's interior. From that shared start, cosmological natural selection and the turn diverge on three points: the number of universes, inheritance, and the constants.

The first point is the number of universes. Cosmological natural selection needs a population: every black hole of every universe begins a universe of its own, and the universes that make the most black holes leave the most descendants. In the collection the ends of all black-hole interiors are one end. No comparison made in the epoch in which a black hole forms registers the end of the black hole's interior. The context of the new epoch is formed again, with no prior identity, and the new context keeps no trace of which old region it came from. The book At the Edge of Reality draws the conclusion by Leibniz's principle, as the collection states the principle. "Every possible comparison therefore gives the end of one interior the same verdicts as the end of another, and the ends are one" (At the Edge of Reality, Chapter 11). So there is one next epoch, and not one next epoch for each black hole. The ends are one for black holes that form at any time in the old epoch, early or late, because no comparison of the old epoch registers the end of an interior, and so no clock of the old epoch dates the end. One next epoch is the singular universe that Smolin and Unger argue for. The collection holds the singular universe exactly, with no population of universes beside it.

The second point is inheritance. Selection needs heredity: the constants of a new universe must be the constants of its parent, changed by a small amount. In the collection every distinction of the old epoch ends at the turn. No distinction crosses the turn as a distinction. The new epoch re-

ceives nothing that told one thing from another in the old epoch: no value, no record and no identity of a region. The book At the Edge of Reality says of the new epoch's context: "I take that context to register no distinction that the old outside world drew, so no comparison of the new epoch registers from which interior any part of its content came" (At the Edge of Reality, Chapter 11). Every count has a context, so no count reckoned in the old epoch is carried across the turn (The Compactification, Chapter 3, Section V). Because no parent is registered, there is no lineage for selection to act on.

The third point is the constants. In cosmological natural selection the constants are what varies and what is selected. In the collection the axioms fix the structure of physics in every epoch, and the structure does not vary at all. For the measured ratios, the collection's own results are true whether or not the ratios repeat from epoch to epoch. One example is the collection's rule for the amount of dark matter, the matter known only by its gravitation. The Weight of Possibility notes that the rule "does not depend on whether the ratios of the content repeat, since the identity concerns what the present measurement registers" (The Weight of Possibility, Chapter 3, Section I).

Smolin's proposal deserves its credit, for two things. Smolin took the black-hole origin of a universe and made the origin explain something, the values of the constants, and he made claims about the origin that a measurement could bear on. The collection takes the same origin and uses it to explain the structure of physics instead. The collection's argument needs neither a population of universes nor a lineage.

## VI. Loop Quantum Gravity and the Arena

Loop quantum gravity raises an objection to the collection's claim that the arena is not quantized. The collection states the objection at full strength. The Unquantized Arena, Chapter 4, Section III, states the objection this way: "That program finds discrete spectra for the operators of area and

volume (Rovelli and Smolin 1995; Ashtekar and Lewandowski 1997), and its proponents read those spectra as a discreteness of geometry itself". In quantum theory each measurable quantity has an operator, and the spectrum of the operator is the set of values that measuring the quantity can give, and a discrete spectrum is a set of separate values with gaps between them. Rovelli and Smolin call the spectra predictions for hypothetical measurements of the geometry of space at the Planck scale, the scale at which an object's gravitational size equals its quantum size.

The collection answers the objection at the premise on which the objection rests. The Unquantized Arena says: "The spectra are spectra of operators defined after the arena has been quantized". The operators are well defined, because they are finite, independent of any background and unchanged under every change of coordinates. The question is what the operators are operators on, and the operators are operators on a quantized arena. The collection holds that the arena is not quantized, and it says exactly what an unquantized arena is: "(i) The arena has no least step: no least length, area or duration. (ii) Nothing is a quantum of the arena itself, at any scale" (The Unquantized Arena, Proposition 6.3). The ground is the Incommensuration Theorem. Gravity is the context of every finding, and the context is continuous and uneven. Content, in physics, is discrete and governed by symmetry. If someone described the context in the character of content, the description would pair what the Incommensuration Theorem forbids to pair: one description of space and time would carry both the continuity and unevenness of the geometry and the discrete sameness of quanta.

The measurements made so far agree with the collection's claim that the arena has no least step. A granular arena is an arena made of least steps. Many models of a granular arena make light of different energies travel at slightly different speeds, so that photons of different energies from a distant burst of gamma rays arrive at different times. No such difference in arrival times has been seen. A first-order effect is a delay in direct proportion to the energy of the photon. The Planck energy is the energy of the Planck scale. The Fermi space telescope recorded a photon of

31 GeV from the burst GRB 090510. GeV is a unit of energy used for particles. That one photon puts the energy at which a first-order effect would appear above 1.2 times the Planck energy (Abdo and colleagues 2009). LHAASO, a gamma-ray observatory in China, observed the burst GRB 221009A, and the observations put the energy of a first-order effect above ten times the Planck energy (Cao and colleagues 2024). The Unquantized Arena, Chapter 19, sets out both bounds. The collection predicts no spread of arrival times at any energy, for two reasons. The arena has no least step, so no spread comes from a step, and by Proposition 5.3 of The Unquantized Arena, no spread comes by any other route either, as Section IX sets out.

Smolin himself wrote in 2001 of how far the programs of quantum gravity remained from what they were meant to achieve, as the collection's book What Cannot Be reports (Smolin 2001). The collection holds that the reason is the same in every program of quantum gravity: in each program, physicists attempt to give the arena the character of its content, that is, to treat space and time as made of quanta, as matter is made of quanta.

## VII. Quantum Theory, Complete in Its Scope

The postulates of quantum mechanics are its basic rules, which textbooks state without proof. Smolin and the collection agree that the postulates, as usually taught, explain nothing about where the postulates come from. Smolin concludes that quantum mechanics is incomplete, and that physicists must find a realist theory beneath it. The collection derives the postulates instead. The Quantum Passage obtains three of the postulates from the structure of comparison. The three postulates are the algebra of quantum observables (the rules by which measurable quantities combine), the Hilbert space of states (the space in which each quantum state is an arrow), and the Born rule (the rule for the probability of each outcome). The measurement problem is the puzzle of how a measurement

comes to have one outcome. The Quantum Passage finds that the measurement problem comes from treating an update of the shared record as a physical process: "the state update upon measurement is not a physical process. It is not an additional dynamical law". The correlations of quantum mechanics exceed the bound that any shared origin of definite values obeys, so a hidden layer of definite values beneath the quantum description cannot produce the correlations (The Basis of Physics, Why Hidden Variables Cannot Help). Smolin's realism and the collection's realism agree that the world is real and is not made by being observed. Smolin and the collection differ on whether quantum mechanics is missing something. On the collection's account quantum mechanics is complete in its scope: quantum mechanics is the theory of content, as general relativity is the theory of context.

## VIII. Time and Space Both Counted

In his later work Smolin takes time as fundamental, and takes space as something that emerges from relations among events. The collection counts the dimensions of time and of space from one source, the structure of comparison. Measurement, Chapter 4, Section VIII, gives two arguments for the count, and the second argument runs as follows. The second axiom orders the three roles of comparison in a cycle with three transitions: from the stance to the act, from the act to the laid-out finding, and from the laid-out finding to a new stance. The collection identifies each of the three transitions with an independent direction of extension, and so gets the three directions of space. The cycle itself has one direction, the order in which it returns to its start, and the collection identifies the one direction of the cycle with the one direction of time. When the structure of comparison is counted, the count produces time and space alike, so time is not prior to space, and space does not emerge from time. Time is real for the same reason that space is real: comparison has the structure of a cycle with three transitions and one direction.

## IX. Where the Predictions Part, and Why

The registered predictions of 1 November 2026 differ from Smolin's own work in four places: in each place the two say that experiment will find different things. The sealed record is the register *The Registered Predictions of Physics from Comparison*, and Volume One reproduces the sealed record whole as its Appendix B. For each of the four places, this section sets the argument of the collection's book on which the sealed prediction rests beside Smolin's own reasoning, and then finds the first premise or step at which the two arguments part. Where both arguments follow from their premises and the premises differ, the section names the premise in dispute and what would settle the dispute. Where a step on either side does not follow, the section names the step. In the quotations of this section, "the account" is physics from comparison.

### Discrete area and volume

**The sealed prediction.** The sealed record says: "No discrete spectrum of area or volume will be observed, in the echoes of gravitational waves from merging black holes or anywhere else". The sealed record registered the sentence on 1 November 2026 as the second sentence of Prediction 5.

**The argument of the book.** The Unquantized Arena, Chapter 6, Section II, sets out the argument as a chain of steps, with what each step rests on. The first step is that the law of continuity governs context, and gravity is the context of physics, its arena. So the findings of the arena "take smooth values with no gaps" when the findings are perfected at their foundation (Proposition 4.2). To quantize the arena would give one description of the arena the continuity and asymmetry of the context together with the discontinuous symmetry of a quantized finding. And so "it would carry at least one of the two forbidden pairings" (Proposition 6.1). The two forbidden pairings are the two that the Incommensuration Theorem forbids: symmetry with continuity, and asymmetry with discontinuity. For area and volume, Proposition 6.3 draws the conclusion. "A least step

of the arena would be a discontinuity in its findings, and by the law of continuity and Proposition 4.2 the findings of the arena have none at their foundation" (Proposition 6.3).

**His argument.** Rovelli and Smolin (1995) start from general relativity written in Ashtekar's variables (a rewriting of the theory, due to Abhay Ashtekar, in which the geometry is carried by a field of the kind that carries the other forces). Rovelli and Smolin then quantize general relativity with no background, that is, with no geometry given in advance, as physicists quantize any field with dynamics of its own. The states of the quantized geometry are spin networks (graphs whose edges and nodes carry labels of spin). Rovelli and Smolin define operators on the spin networks for the area of a surface and the volume of a region. The operators have discrete spectra. Rovelli and Smolin read the discrete spectra as the geometry of space at the Planck scale.

**Where they part.** The two arguments separate at the first premise. For Smolin, the geometry is a field with dynamics, like the fields of the other forces. So the geometry has quantum states of its own. For the collection, the geometry is the context in which every finding is made, and the law of continuity governs the geometry.

**Whose step, and what decides it.** Each chain of steps follows from its own premises. So the difference between the chain of steps of loop quantum gravity and the chain of steps of the collection is a premise. The premise can be stated in one sentence: the geometry of space and time is the context of every finding, and not one more content found within the geometry. The premise is a claim about what the geometry of space and time is. The sealed record lists the observations that bear on the premise: "every observation of the spectrum of area or volume". The effective field theory of gravity is the standard theory that treats gravity as a quantum field at low energies. The sealed record states that "Below the Planck curvature the account and the effective field theory of gravity give the same result for every experiment now proposed". So a measurement of geometry at the Planck scale is what would separate the two premises.

Apart from anything the collection says, loop quantum gravity has one open step on its own ground. The open step is the step from the computed spectra to a discreteness that a measurement would find. The quantum constraints are the equations that every physical state of the quantized theory must satisfy. Two operators commute when the order in which they are applied makes no difference. The operators whose spectra are discrete do not commute with the quantum constraints. The physicists Bianca Dittrich and Thomas Thiemann (2009) showed, in simpler models, that "kinematical discreteness of the spectrum does not necessarily survive at the gauge invariant level": a discreteness found before the constraints are applied can be lost once the constraints are applied. Rovelli (2007) replied that the counter-example of Dittrich and Thiemann "illustrates a pathology which does not seem to be present in gravity". So the open step has not been completed inside loop quantum gravity either. On the collection's side, The Unquantized Arena already says exactly where the spectra belong. The spectra "belong to the step whose coherence Chapter 6 examines" (Chapter 4, Section III): the step of quantizing the arena. The two arguments rest on different premises, and I find no fault on either side.

### The speed of light at every energy

**The sealed prediction.** The sealed record says: "The speed of light in vacuum does not depend on the energy of the light through any step of spacetime". The sealed record registered the sentence on 1 November 2026 as the first sentence of Prediction 5.

**The argument of the book.** The Unquantized Arena, Chapter 19, Section V, gives the route by which a dependence of the speed of light on energy would come: "A step of spacetime would generally change the relation between energy and momentum of light at high energy". The arena has no step (Proposition 6.3), so the route through a step of spacetime is closed, and "the account says that the arrival times will show no such dependence". Lorentz invariance is the symmetry of special relativity: each

observer who moves at a steady speed finds the same laws and the same speed of light, and a dispersion of light is a spread of its speed with its energy. Section V of Chapter 19 adds that "A discreteness that keeps Lorentz invariance, as in causal sets (Bombelli, Henson and Sorkin 2009), predicts no such dispersion", where a causal set is a model of spacetime as a set of discrete events ordered by cause. The same section of Chapter 19 says that the step tested by the timing of photons from bursts "is the category error of Chapter 6: that the arena is not quantized and has no least step".

Section V of Chapter 19 also shows that every other route is closed, on a ground that uses no step at all. "Light of every energy follows the light cone of the one geometry, and the account's ground for that uses no step of spacetime" (The Unquantized Arena, Chapter 19, Section V). The light cone of an event is the set of paths that light can take from the event. The ground is Proposition 5.3: "the coupling of every content to the arena equals its inertia, and the ratio is the same for every content". The coupling of a content to the arena is the strength with which the arena acts on the content, and inertia is the resistance of the content to a change in its motion. Proposition 5.3 therefore means that "the free path of a content through a geometry is set by the geometry and not by the mass or the energy of the content". For light the free path is the light cone, "and within one geometry the light cone is the same in every frame" (Chapter 7, Section IV, in the argument of Proposition 7.2). A frame is one observer's way of laying out space and time. In *The Unquantized Arena* I conclude: "A speed of light that depended on the energy of the light would give light of each energy its own free path through one geometry, set by a property of the content, and the equal ratio of Proposition 5.3 excludes that, whether the dependence came from a step of spacetime or from some other source".

The collection's book The Unquantized Arena identifies Smolin's route as one such other source: "a deformed symmetry of special relativity that keeps, beside the speed of light, a second quantity the same for every observer, an energy of the order of the Planck energy, set into the symmetry itself and not into a step of spacetime (Magueijo and Smolin 2002)". The

Unquantized Arena excludes the versions of the deformed symmetry in which the speed of light depends on the energy of the light, and it excludes them "on the ground just given".

**His argument.** Smolin takes a different route to a speed of light that depends on energy. An invariant is a quantity that every observer finds the same. The Lorentz group is the set of changes of view between observers moving at steady speeds. Smolin and the physicist João Magueijo proposed that "a physical energy, which may be the Planck energy, joins the speed of light as an invariant", through "a non-linear modification of the action of the Lorentz group on momentum space" (Magueijo and Smolin 2002). Poincare invariance is Lorentz invariance together with the sameness of the laws at every place and every time. Smolin and the physicist Giovanni Amelino-Camelia then set out how the photons of gamma-ray bursts can bound or measure a dispersion of light that comes "from breaking or deforming of Poincare invariance" (Amelino-Camelia and Smolin 2009). On Smolin's route, the speed of light depends on energy because the symmetry of the arena is deformed. The dependence needs no least step.

**Where they part.** For the collection, the geometry alone sets the free path of light through the geometry, because the coupling of every content to the arena equals the inertia of the content. So light of every energy follows the one light cone. For Smolin, the symmetry of the arena can be deformed so that the deformed symmetry keeps an energy invariant, and the speed of light can then depend on the energy of the light with no least step.

**Whose step, and what decides it.** Both chains follow from their premises, and the premise in dispute can be stated in one sentence: light of every energy moves on the light cone of the one geometry, so no symmetry of the arena, kept or deformed, makes the speed of light depend on the energy of the light. The collection holds the premise on the ground of Proposition 5.3. Proposition 5.3 applies alike to the step of spacetime that the sealed sentence names and to a deformed symmetry. Smolin's route has its own difficulty, on its own ground, and The Unquantized Arena

credits the work that shows the difficulty. The physicist Sabine Hossenfelder (2010) showed that a speed of light that depends on energy in the same way for every observer has non-local effects, in which what happens at one place depends on what happens far away. Hossenfelder keeps the non-local effects within the limits of known particle physics, and so she can "rule out a modification to first order in energy over the Planck mass". Hossenfelder later named a second difficulty: "The most pressing problem in these models is the treatment of multi-particle states, known as the 'soccer-ball problem'" (Hossenfelder 2014). Everyday bodies, such as a soccer ball, are made of many particles, and the total energy of such a body is far above the Planck energy, so the deformed symmetry would show large effects in the motion of everyday bodies, and no such effects are seen. In the same Section V of Chapter 19, The Unquantized Arena states that "The timing bounds of Table 19.2 test a deformed symmetry and a step of spacetime alike".

Measurement has already reached the scale that Smolin's route names, the Planck energy. For a dependence of the first order, one photon of the burst GRB 090510 puts the energy at which the dependence would appear above 1.2 times the Planck energy (Abdo and others 2009). Several bursts put the energy above 7.6 times the Planck energy (Vasileiou and others 2013). The burst GRB 221009A puts the energy above ten times the Planck energy (Cao and others 2024). Section VI reported the first bound and the third, and The Unquantized Arena sets out all three. All three bounds come from one kind of measurement, the timing of photons from bursts. The registered predictions have a rule of decision: a result counts when it is established at five standard deviations by at least two independent kinds of measurement. A standard deviation is the usual measure of the size of chance errors in a measurement. The rule requires two independent kinds of measurement, so the three bounds together count as one kind of evidence toward a decision. A dependence of the second order is a delay in proportion to the square of the energy of the photon. A dependence of the second order is bounded only at energies far below the Planck energy. No measurement yet tests a dependence of the second order at the

Planck energy. Neutrinos are light, neutral particles that bursts also send out. Amelino-Camelia and Smolin proposed timing the neutrinos from bursts, and that timing would give the second, independent kind of measurement.

### Quantum statistics for states without precedent

**The sealed prediction.** The sealed record says: "Repeated measurements on identically prepared systems settle to the weights of the Born rule, in every sector and on the full space, including in the tests proposed for superdeterminism, which look for departures from those weights". The sealed record registered the sentence on 1 November 2026 as Prediction 25.

**The argument of the book.** The Quantum Passage, Chapter 7, derives the weights of the Born rule in three layers. In the first layer, the outcome of a measurement is a residual by the Incommensuration Theorem: what is left of a finding once every law has been applied, which no law fixes. The Quantum Passage puts the first layer this way: "the state before the measurement, known as fully as the theory allows, gives the weight of each outcome, and the outcome found is not contained in it". In the second layer, a probability is "the stable relative frequency of an outcome over repetitions of one comparison" (Section IV). In the third layer, "The single weight of a finding follows from the law of symmetry" (Section VI). The mathematician Andrew Gleason proved that every consistent assignment of weights to outcomes has the form of the Born rule, on a space of states of three or more dimensions. So, by Gleason's theorem, the Born rule is the only measure.

A law, in the collection, states what stays the same when the circumstances of a measurement change (Section III above). The number of times a measurement has been made before is one of the circumstances of the measurement. The law of symmetry alone fixes the weight of an outcome (The Quantum Passage, Chapter 7, Section VI), so the weight is the content of a law. The content of a law stays the same across every change

of circumstance, including a change in the count of earlier instances. So the weight that the state gives an outcome is the same at the first finding as at the millionth.

**His argument.** Smolin (2012b) proposes that "the outcome of the present measurement is determined by picking randomly from the ensemble of precedents of that measurement". Where a measurement has no precedents, no habit has formed: "The first several iterations of a novel state are not determined by any law". In Smolin's real ensemble formulation of quantum mechanics (Smolin 2012a), a quantum state describes a real collection of similar systems in the universe. The real ensemble formulation likewise implies departures from quantum mechanics for states expected to have few copies in the universe.

**Where they part.** The two arguments differ on what determines the weight of a first finding. The collection holds that the present state of the system determines the weight, whether or not the measurement has been made before. Smolin holds that the record of earlier instances determines the weight, and a first instance has no earlier instances.

**Whose step, and what decides it.** Each step on each side follows from its premises, and the difference is the premise about what determines the weight of a first finding. Setting the two arguments side by side gives two results, one on each side. On Smolin's side, the principle of precedence contains no rule for which earlier instances count as the same measurement. Smolin writes that the principle "takes the notion of copy, or similar preparation or measurement, as a primitive" (Section 4), that is, as a notion that the principle does not define. An entangled state is a joint state of parts whose quantum states are linked, so that no part can be described on its own. Take an entangled state that is new, made of parts that have each been prepared countless times. The state can be counted either as new or as old. So Smolin's principle predicts a departure for a named experiment only once a rule of sameness is given. On the collection's side, the sealed sentence of Prediction 25 speaks of what repeated measurements "settle to". Smolin's principle allows the same long-run weights once precedents have formed. So the collection and Smolin differ in the

first outcomes. The Quantum Passage addresses the first outcomes, in its words that the state "gives the weight of each outcome". The sealed sentence of Prediction 25 leaves the first outcomes aside.

The two statements together give the measurement that would decide: the first outcomes of many distinct states, each state prepared for the first time and measured once, pooled and compared with the weights each state gives. The sealed record does not contain the design of a measurement of first outcomes. The nearest measurement made so far is the sampling of random circuits on a superconducting quantum processor (Arute and others 2019). Each circuit was new, and each circuit was sampled between half a million and two and a half million times. The system fidelity is how closely the outputs of the processor match the outputs that quantum mechanics predicts for the circuit. The authors report that their "system fidelity is well predicted by a simple model" built from the errors of single gates and measurements. Arute and others measured the long-run weights of states without precedent, and not the first outcomes of those states.

### Galaxies at low acceleration

**The sealed prediction.** The sealed record says: "A galaxy falling freely in the field of a larger one feels that field only through its tide; the external field effect that modified Newtonian dynamics predicts will not be found". The sealed record registered the sentence on 1 November 2026 as Prediction 24. The tide of a field on a galaxy is the difference between the pull of the field on the near side of the galaxy and its pull on the far side. Modified Newtonian dynamics is a law of gravity that departs from Newton's law below a fixed value of acceleration. The external field effect is the prediction of modified Newtonian dynamics that a system falling freely in the field of a larger one moves differently because of that field, beyond the tide of the field.

**The argument of the book.** The Weight of Possibility, Chapter 5, Section V, takes up the measured acceleration scale of the galaxies, the acceleration below which the motions in galaxies depart from Newton's law applied to their visible matter. The cosmological constant is an energy of empty space that never changes, and in The Weight of Possibility, Chapter 5, Section V, I ask whether the cosmological constant sets the acceleration scale. The field equations are the equations of general relativity. In the same section I answer: "The field equations hold Newton's constant and the cosmological constant, and no constant of acceleration". The cosmological constant draws two free bodies apart with a pull that comes to "about $1.0 \times 10^{-15}$ meters per second per second across ten kiloparsecs, the size of a galaxy, which is less than a hundred-thousandth of the scale". So in the same section I conclude: "With the field equations exact throughout the domain of the smooth description, below the Planck curvature, as the Passage derives them, a galaxy falling freely in the field of a larger one feels that field only through its tide, as general relativity requires". In that sentence "the Passage" is the collection's book The Gravitational Passage.

The conclusion rests on the equality of gravitational and inertial mass, which the collection derives. Gravitational mass is how strongly gravitation pulls a body, and inertial mass is how strongly the body resists a change in its motion. The Unquantized Arena, Proposition 5.3, states: "For a context-modal phenomenon, the coupling of every content to it equals that content's inertia". A context-modal phenomenon is one that belongs to the context, the arena, and not to the content found in the context. Proposition 5.3 gives its reason: "for the context there is only the one relation, so the coupling and the inertia have nothing to differ by". The Weight of Possibility applies Proposition 5.3 to gravitation, which "is a distortion of a context", and draws the consequence: "That holds at every acceleration and in every environment, so the ratio of gravitational to inertial mass is one everywhere, and no temperature of the horizon enters inertia apart from weight". The cosmic horizon is the boundary beyond which light can never reach an observer. The de Sitter temperature is the temperature

of the horizon of a universe with a positive cosmological constant. The de Sitter temperature is the least temperature an observer in that universe can see. Smolin (2017) proposed that the horizon sets the scale through the de Sitter temperature. In The Weight of Possibility, Chapter 5, Section V, I answer Smolin's proposal, "the second route by which the horizon has been proposed to set the scale", with the statement that the ratio is one everywhere.

In Section V of Chapter 5, the collection also accounts for the tightness of a relation between the visible matter and the motions of galaxies. Astronomers measure the acceleration scale in that relation. "The tightness of that relation follows from galaxy formation under general relativity with a cold component that acts only through gravity, and the account inherits it because the gyrations are such a component". A cold component is matter that moves slowly compared with light. The gyrations are the collection's dark matter: conserved excitations of the six held internal dimensions (kept at the same size and shape at every point), each of about the Planck mass. In the same section of The Weight of Possibility I continue: "Simulations of galaxy formation with such a component reproduce the relation and its small scatter (Keller and Wadsley 2017; Ludlow and others 2017; Dutton and others 2019)". A halo is the cloud of dark matter around a galaxy. In the same section of The Weight of Possibility I state that the relation originates in "the self-similar profiles of cold halos, in the narrow range of halo mass in which disc galaxies form, and in the slow relaxation of the dark component around the gathering ordinary matter (Navarro and others 2017; Paranjape and Sheth 2021)". The acceleration at which the relation turns is the acceleration at which the relation bends away from Newton's law applied to the visible matter. So "The acceleration at which the relation turns is therefore set by formation and not by a constant of the field equations, and the clusters of galaxies show it: there the same form turns at $(2.02 \pm 0.11) \times 10^{-9}$ meters per second per second, about seventeen times the galactic value (Tian and others 2020; Tian and others 2024)".

**His argument.** Smolin (2017) builds on a hypothesis of the physicist Erik Verlinde. Verlinde's hypothesis is that gravity is entropic: gravity arises from the growth of entropy, as the flow of heat does. Smolin takes inertia to arise from how well a particle can be localized, that is, confined to a small region. In a world with a positive cosmological constant, an accelerated body sees a temperature. The cosmic horizon has an irreducible temperature of its own, the de Sitter temperature. Smolin takes the response of a body to acceleration from the excess of the temperature the body sees over the de Sitter temperature. On Smolin's choice, the ratio of inertial to gravitational mass equals the acceleration divided by the de Sitter scale of acceleration. The equality holds wherever the acceleration falls below the de Sitter scale. The de Sitter scale of acceleration is the speed of light squared times the square root of the cosmological constant. In the limit Smolin takes, the ratio of the two masses gives Milgrom's law, the law of modified Newtonian dynamics that the physicist Mordehai Milgrom proposed. On Smolin's proposal, free fall stays the same for every body at one place. But the ratio of inertial to gravitational mass "can depend on global or environmental parameters". Smolin presents the proposal as a tentative one (Smolin 2017, Section 6).

**Where they part.** For the collection, a body's inertia and its weight are one relation of the body to its context, found twice, so the ratio of inertia to weight is one at every acceleration. For Smolin, inertia is a thermal response that also depends on the temperature of the cosmic horizon. So the ratio of inertial to gravitational mass falls below one at accelerations under the de Sitter scale. Both the collection and Smolin keep free fall the same for every body at one place, so the measurements that test whether bodies of different composition fall alike do not separate the collection from Smolin.

**Whose step, and what decides it.** Both chains follow from their premises. The premise in dispute is that the inertia of a body is the same relation to its context as the weight of the body, at every acceleration, with nothing added from the temperature of the cosmic horizon. The premise is a claim about what inertia is, and measurements of motions at low ac-

celeration bear on the premise. Wide binary stars are pairs of stars that orbit each other far apart. Each star of a wide binary pulls on the other at a very low acceleration. The Gaia satellite maps the positions and motions of stars. Banik and colleagues analyzed the wide binaries that Gaia measured, and they found Newtonian dynamics preferred over the modified dynamics "at 19$\sigma$ confidence", that is, at nineteen standard deviations (Banik and others 2024). The astronomer Kyu-Hyun Chae reported an anomaly in the wide binaries he selected (Chae 2024), and later, with colleagues, an anomaly in a sample of 36 wide binaries (Chae and others 2026). Saad and Ting reanalyzed the 36 wide binaries with models of their orbits in three dimensions, and they found the 36 binaries consistent with Newtonian gravity (Saad and Ting 2026).

In galaxies, the second kind of measurement would come from a sample analyzed with the external field separated from the surroundings in which each galaxy formed. The separation matters because, on the collection's account, formation sets the acceleration at which the relation between visible matter and motion turns. Chae and colleagues reported an external field effect in 2020 (Chae and others 2020), and they estimated the external field of each galaxy from the neighbors of the galaxy, and they did not separate the external field from the surroundings in which each galaxy formed. In the sealed record, no listed measurement decides Prediction 24. I name two such measurements in this paragraph and the paragraph before it: the wide binaries, and a sample of galaxies analyzed with the external field separated from the surroundings in which each galaxy formed.

## X. Summary

Lee Smolin holds five claims. For Smolin, time is real, and the universe is one. He also holds three more claims: the laws of physics are not a timeless mathematical object outside the world, physics is built from relations, and a universe can begin inside a black hole. The physics collection holds

all five of Smolin's claims, from the structure of comparison. On the collection's account, time is the direction in which comparison proceeds, and the universe is a process, one sequence of epochs. No description is made from outside the universe, and relation is the one premise. The end of each black-hole interior is the turn to the next epoch. Smolin and the collection share Leibniz's principle. The collection states the principle as a fact about comparison: a difference that no comparison can register is no difference.

Smolin and the collection differ on four points of principle. First, Smolin lets the laws change to keep the future open. The collection keeps the future open with laws that stay the same, because the Incommensuration Theorem forbids any law to be perfected together with continuity. Second, Smolin's universes form a population that inherits and varies its constants, while in the collection the ends of all black-hole interiors are one, and nothing crosses the turn as a distinction. The axioms fix the structure of physics in every epoch. Third, Smolin's arena comes in discrete steps of area and volume, while the collection's arena has no least step, and the measurements of light from distant bursts have so far found no sign of a least step. Fourth, Smolin seeks what is missing beneath quantum mechanics, while the collection derives quantum mechanics and finds it complete in its scope. In each of the four cases Smolin found the right question, and the collection answers the question from the structure of comparison.

When the arguments behind the four differing predictions are set side by side, the arguments part at premises, and not at faulty steps. The four premises are whether the geometry is the context of every finding, whether light of every energy follows the one light cone, what determines the weight of a first finding, and whether inertia is the one relation of a body to its context. One proposition is the collection's ground for both the second premise and the fourth: the coupling of every content to the arena equals the inertia of the content. The one proposition excludes a speed of light that depends on energy, whether the dependence comes from a least step or from a deformed symmetry. The one proposition also excludes any

temperature of the horizon entering inertia apart from weight. On the collection's account, galaxies formed with a cold component, so the relation between visible matter and motion in galaxies is tight. Formation with a cold component also sets the acceleration at which the relation turns. Time is real on both accounts. The collection finds time real in every act of comparison, with laws that need not change to keep time real. Smolin holds that physics went wrong when physicists took their timeless mathematics for the world. In the chapter on Max Tegmark, in Volume Four, I set the model of Max Tegmark beside physics from comparison. Tegmark holds that the world is a mathematical structure. Tegmark argues for that claim from a premise that Smolin and the collection both hold: that there is an external physical reality completely independent of us humans.

**Key Concepts**

- On the collection's account, time is real because comparison runs one way: from the stance, to the act, to the record, and the record shapes the next stance.
- The view from nowhere is real, and the laws of physics are stated in it, but the error is to take the view from nowhere for everything.
- Leibniz's principle, as the collection states it for comparison: a difference that no comparison can register is no difference.
- Smolin's precedence is a memory of instances, while the collection's precedence is the order of every single comparison.
- A law states what stays the same. Determinism cannot be had, so laws that stay the same leave the future open.
- At the turn there is one next epoch, and not a population of universes, and nothing crosses the turn as a distinction. The axioms fix the structure of physics in every epoch.
- The arena is not quantized: it has no least length, area or duration, and nothing is a quantum of the arena at any scale.
- Where the predictions of Smolin and the collection differ, the two accounts part at premises: whether the geometry is the context of every finding, whether light of every energy moves on the one light cone, whether the present state determines the weight of an outcome, and whether inertia and weight are one relation.

## Terms

**Content and context.** In every comparison, what is found and the arena it is found in; in physics, quantum matter and the geometry of general relativity.

**Cosmological natural selection.** Smolin's proposal that each black hole begins a new universe whose constants differ slightly from the constants of its parent universe, so that universes that make many black holes predominate.

**De Sitter temperature.** The temperature that the horizon of a universe with a positive cosmological constant has, the least temperature an observer in that universe can see.

**Deformed special relativity.** A proposal, made by Magueijo and Smolin and by Amelino-Camelia, that an energy, perhaps the Planck energy, is the same for every observer as the speed of light is, with the symmetry of the arena changed at high energy to keep that energy the same for every observer.

**External field effect.** The prediction of the modified Newtonian dynamics that a system falling freely in the field of a larger one moves differently because of that field, beyond the tide of the field.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Inertia.** A body's resistance to a change in its state of motion; in the collection, the same relation of the body to its context as the body's weight, found a second time.

**Loop quantum gravity.** A program that quantizes the geometry of space without a fixed background, in which areas and volumes take discrete values.

**Principle of precedence.** Smolin's proposal that the outcome of a quantum measurement is drawn from the outcomes of earlier instances of the same measurement.

**Root Tautology.** Comparison, interaction and relation are one act under three names.

**Rule of decision.** The rule of the registered predictions: a result counts when it is established at five standard deviations by at least two independent kinds of measurement.

**Second axiom.** The directed cycle of the three roles of comparison, an order of precedence and not of clock time, converging from many to one at each step.

**Stance.** The side from which a comparison is made; the stance belongs to every comparison, human or not.

**The turn.** The passage from the end of one epoch of the universe to the beginning of the next, at the end of every black-hole interior; no comparison registers the turn as an event.

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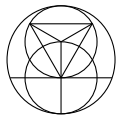

Ilya Prigogine

# The Arrow Comes First

*Ilya Prigogine, Irreversibility and Physics from Comparison*

## Abstract

Ilya Prigogine was a chemist who won the Nobel Prize in Chemistry in 1977. Prigogine spent half a century arguing for four conclusions: that the direction of time is real, that irreversible processes build order as well as destroy order, that probability cannot be removed from the description of unstable systems, and that determinism fails. An irreversible process runs one way only, as heat flows from a hot body to a cold one. Determinism is the view that the state of the world at one moment, together with the laws of physics, fixes every later state. The physics collection of the Immanent Metaphysics is the set of books in which I set out physics from comparison. I call the physics collection the collection for short. The collection holds all four of Prigogine's conclusions on a single ground: the Incommensuration Theorem, which forbids perfecting symmetry and continuity together. Symmetry is a sameness that holds across a change, as one law holds at every place and every time. Continuity is a connection without a break. On chance, the collection holds that chance cannot be removed from the world. But the collection parts from Prigogine on whether chance belongs to the laws of physics (Section V). A deterministic world would need perfect symmetry with perfect continuity, the very

pairing that the Incommensuration Theorem forbids. So no world is purely deterministic, whether the dynamics of the world are stable or unstable.

Prigogine reached his conclusions by studying a class of dynamical systems, the large Poincaré systems. A trajectory is the exact path of a system through its states over time. In a large Poincaré system, resonances among the motions make a description by trajectories fail. Prigogine then built irreversibility into the laws: out of two possible evolutions, he chose the evolution that runs toward equilibrium in the future. Equilibrium is the state in which a system has stopped changing, as hot coffee cools to the temperature of the room. The collection finds the laws symmetric in time to an extraordinary degree, but never perfectly. The collection finds the arrow of time beneath the laws. Symmetric laws guarantee that a reversed process is lawful. Symmetric laws never guarantee that the reversal is faithful, that is, that the reversed process retraces exactly the states of the original process, because faithful reversal needs the pairing that the Incommensuration Theorem forbids. In this chapter I set out what Prigogine established and on what ground the collection holds his conclusions. I then set out where Prigogine and the collection differ about the place of irreversibility and chance. Last, the chapter shows how the collection's two arrows of time settle the long dispute between Prigogine and the followers of Ludwig Boltzmann.

## I. A Chemist Against Determinism

Ilya Prigogine (1917 to 2003) received the Nobel Prize in Chemistry in 1977 "for his contributions to non-equilibrium thermodynamics, particularly the theory of dissipative structures". Thermodynamics is the science of heat and energy, and non-equilibrium thermodynamics studies systems that never settle into equilibrium, because energy keeps flowing through the systems. A *dissipative structure* is an ordered pattern that exists only because energy and matter keep flowing through the pattern, far from equilibrium. Two examples are the hexagonal cells that appear in a fluid

heated from below and the colored waves that travel through the Belousov-Zhabotinsky reaction, a mixture of chemicals whose color changes back and forth. Prigogine's Nobel lecture of 8 December 1977 was titled "Time, Structure and Fluctuations", and the title states his program. The program makes two claims. First, irreversible processes can also be the source of order, although classical thermodynamics treated irreversible processes as leading only to disorder. Second, a system far from equilibrium can reach a point at which the system must settle into one of several possible patterns. A fluctuation is a small chance departure from the average. At the point where the system must settle, a fluctuation decides which pattern appears.

Prigogine carried his argument to a general audience in two books, written with the philosopher Isabelle Stengers. The books are *Order Out of Chaos* (1984) and *The End of Certainty* (1997; French original 1996). *The End of Certainty* states its conclusion in one sentence: "The more we know about our universe, the more difficult it becomes to believe in determinism". The two books drew on a technical program, which Prigogine pursued with the physicist Tomio Petrosky and the Brussels-Austin group of researchers. The program studied *large Poincaré systems*: systems with a continuous set of resonances among their motions. A resonance occurs where two motions of a system have frequencies in a simple ratio, so that the two motions keep exchanging energy. In the equations of a large Poincaré system, the resonances produce divergences, terms that grow without limit. The divergences can be removed only by passing to a new description. Petrosky and Prigogine (1993) put the result in these words: the removal of the resonance divergences "leads to complex irreducible spectral representations", and "irreducibility means that this representation is implementable only by statistical ensembles and not by trajectories". A statistical ensemble is a distribution of probability over many possible states of a system. Petrosky and Prigogine put the consequence in a phrase: "Complex means that time symmetry is broken". Time symmetry is the sameness of a law whether time runs forward or backward.

The evolution of a system is the way the system's state changes over time. The Brussels-Austin group set the evolution in an extended mathematical space (a rigged Hilbert space). In the extended space the evolution splits into two semigroups, which are evolutions that run in one direction of time only. One semigroup approaches equilibrium toward the future, and the other approaches equilibrium toward the past. The group chose the semigroup that approaches equilibrium toward the future. Earlier accounts had treated irreversibility and probability as by-products of approximation or of ignorance, while on the group's account irreversibility is part of the dynamics and probability is part of the law.

## II. What Prigogine Established

The collection holds four of Prigogine's conclusions, and the collection states each conclusion in its own words.

The first conclusion is that determinism fails, and so the future is open: the present state of the world does not fix what will happen. Causality Without Determinism, Chapter 1, Section IX, states the failure of determinism as the non-polarization principle: "All worlds are to some non-zero and positive degree causal. No world is purely and completely deterministic". In the principle, a causal world is a world in which each event is connected to what came before the event. A purely deterministic world is a world in which what came before fixes every event completely. Measurement, Chapter 12, Section V, states the openness of the future. A description written from the third person is written as an outside observer would write it, and what a third-person description leaves out "is newness, and a description in mathematics, which is deterministic, cannot contain newness". A stochastic description states probabilities for outcomes, and Section V of this chapter shows why a stochastic description is no exception.

The second conclusion is that the arrow of time is real. Incommensuration, Chapter 8, Section X, states: "The structural arrow of time is the result that perfect time-reversal symmetry is impossible", and "The direction

of time is the direction in which comparison proceeds". The collection treats comparison, interaction and relation as one act under three names. So every physical interaction is a comparison. Section IV of this chapter sets out the order in which a comparison proceeds.

The third conclusion is that chance cannot be removed. The Basis of Physics, Essay 6, calls the chance that cannot be removed *hard randomness*: "a phenomenon that could not be predicted on the basis of any past knowledge, because no causal prediction capacity exists for it". Essay 6 places hard randomness at the edge of the domain of measurement, the boundary below which nothing can be measured, and Essay 6 shows hard randomness amplified, made larger and carried upward, by every process that is sensitive to small differences.

The fourth conclusion is that irreversible processes build order. A system far from equilibrium can reach a branching point, a point at which the system can take any one of several patterns. At a branching point the event itself settles which branch the system takes, and no law laid out in advance settles the branch. Once the system has taken the branch, everything that follows on the branch is lawful. Section VI of this chapter sets out how the collection accounts for the order of a dissipative structure at a branching point.

Prigogine reached the four conclusions as a physical chemist, from work in the laboratory and from the mathematics of unstable systems, and he reached the four conclusions against the settled view of his field. Prigogine held the four conclusions for fifty years. The four conclusions are correct, and the collection argues for every one of the four.

## III. Why Determinism Cannot Be Had

Prigogine's argument against determinism rests on instability. A system is unstable when small differences in its state grow quickly over time. In an unstable system, a trajectory diverges from its neighbors at an exponential rate, moving away ever faster from the trajectories that start near it, so no

finite specification of the starting state can follow the trajectory. In large Poincaré systems the resonances make the description by trajectories fail altogether. The argument from instability is strong where the argument applies, and the argument applies to one class of systems: the systems that are unstable enough, and whose resonances are dense enough, for the description by trajectories to fail.

The collection's argument against determinism applies to every world, stable or not, and the argument begins with what determinism requires. The Basis of Physics, Essay 2, Section III, says plainly what determinism requires. The determinist holds that the world has a specification that "is everywhere continuous: no gaps, no missing values", and that "is everywhere symmetric: the same laws hold in every context". Essay 2 concludes: "Determinism is therefore the assertion of total symmetry and total continuity, applied simultaneously and without remainder. That is the first forbidden conjunction of the theorem, named without alteration". The theorem in the quotation is the Incommensuration Theorem: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The theorem therefore forbids two pairings, and the first forbidden pairing is symmetry with continuity. Determinism is the first forbidden pairing, so Essay 2 states that "no world is purely and completely deterministic", and Essay 2 adds: "The conclusion does not depend on the results of any experiment". The Incommensuration Theorem is a structural fact about the nature of knowing.

The Immanent Metaphysics rests on three axioms, and I formulated the first axiom in or before 1991. I formulated the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996. I did most of my work in physics in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the Incommensuration Theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1. The mathematician Pierre-Simon Laplace pictured an intellect that knows the state of every particle and every law. Physicists now call the intellect Laplace's demon, and Laplace's demon could therefore calculate the whole future. Causality

Without Determinism, Chapter 1, Section VIII, puts the result that no world is purely deterministic in the picture of Laplace's demon: the demon "asks for the forbidden top row". The top row is the pairing that the Incommensuration Theorem forbids first, total specification with lawful structure. Total specification is continuity, and lawful structure is symmetry.

When determinism fails, what remains is causation, not nothing. Measurement, Chapter 12, Section IV, gives the reason: "The failure of determinism leaves causation and not nothing, because the pairing that causation has is never forbidden: continuity with asymmetry, a connection without a break along an order that runs one way". Physicists use mathematical descriptions, called formalisms, and the formalisms can stay deterministic at their own level. The quantum state is the complete quantum description of a system, and Chapter 12 reads the deterministic evolution of the quantum state as "the symmetry of the law at its own level", while the findings remain causal and not determined. A finding is an interaction that registers which alternative is the case. An instrument or an environment can make a finding, with no mind needed. Prigogine demanded that the future be open, and the collection's argument shows that the future of every system is open, with no need to wait for a proof that each system is unstable. Prigogine's arguments from instability then have a different role: the arguments show where, inside the domain of measurement, the openness of the future becomes visible at the scale of everyday things (Section V).

## IV. Lawful Reversal and Faithful Reversal

Prigogine's deepest question was about the arrow of time. The fundamental equations of mechanics are symmetric in time: a solution of the equations is a motion that the equations allow, and a solution that is run backward is still a solution. If the equations allow every motion to run backward, why do the processes of the world run one way only? Prigo-

gine answered by changing the dynamics: in the extended description of large Poincaré systems, the evolution splits into two semigroups. Prigogine's group selected the semigroup that runs toward equilibrium in the future. The philosopher of physics Robert Bishop wrote a careful account of the program. Bishop records that the group justified the selection partly by the observed asymmetry of time. So the arrow of time enters Prigogine's account through the very choice that was meant to explain the arrow.

The collection keeps the laws of motion as physics states them. The collection finds the laws symmetric in time to a very high degree, but never perfectly symmetric. The Basis of Physics, Essay 11, Section VII, states the degree: "The laws exhibit time-reversal symmetry to an extraordinary degree, and the argument does not say otherwise. It says the symmetry cannot be perfect". Physicists have already measured the remaining asymmetry, and Section VII of Essay 11 cites three measurements of the asymmetry. The first measurement showed that the weak interaction, the force behind some kinds of radioactive decay, violates the combined symmetry of charge and parity (Christenson, Cronin, Fitch and Turlay, 1964). The combined symmetry of charge and parity is the sameness of every law under one change: each particle is replaced by its antiparticle, and the world by its mirror image. The CPT theorem states that every law of quantum field theory is unchanged when charge, parity and the direction of time are reversed together. By the CPT theorem, the violation of charge and parity symmetry entails a violation of time reversal, and the second and third measurements have since observed the violation of time reversal directly (CPLEAR, 1998; BaBar, 2012). Essay 11 reads the measured violation as "a place where the impossibility of perfecting temporal symmetry has become visible to instruments". Essay 11 is also exact about how much its argument claims: "The argument says that some asymmetry must exist. It does not say how large, in which interaction, or through what mechanism". The sealed record is the register of predictions that I sealed on 1

November 2026, and Prediction 28 of the sealed record registers the requirement: “Some asymmetry of time must exist in the laws, and no process at any scale is perfectly reversible”.

The collection finds the arrow of time itself at a level beneath the laws, and the measured violations are places where the laws show the asymmetry that the arrow of time requires. The measured violations are not the arrow itself. The Basis of Physics, Essay 11, Section III, draws the distinction on which the answer to Prigogine’s question turns. Essay 11 separates two claims about reversal, “and they are not the same claim”. In Essay 11 I state the two claims in these words: “The first is that the laws are symmetric: if a process is lawful, its time-reverse is lawful. The second is that the reversal is faithful: the time-reversed process traces back through exactly the states the original process traversed, and arrives at exactly the original condition”. Essay 11 then states how the two claims differ: “Symmetry of the laws guarantees lawful reversal. It does not guarantee faithful reversal”. Faithful reversal needs every aspect of the state captured with no gap, which is perfect continuity. When a symmetric law acts on a state specified with no gap, the law and the state together are perfect symmetry paired with perfect continuity, the conjunction that the Incommensuration Theorem forbids. The abstract of Essay 11 states the consequence: “Perfect time-reversal is therefore precluded, and the preclusion depends on no entropy, no boundary condition, no Past Hypothesis, and no particular formalism”. Entropy is the measure of disorder that grows in large systems. A boundary condition is a condition set at the start or at the edge of a system. The Past Hypothesis is the assumption that the universe began in a state of very low entropy.

The arrow beneath the laws is the structural arrow: the direction in which comparison proceeds. Every comparison runs from the range of what is possible, through the act of comparing, to the record that the act leaves, and the record then shapes the range of what is possible for the next comparison. In a measurement, for example, the range is the set of results the instrument could show. The act is the instrument’s interaction with what it measures, and the record is the result the instrument shows.

The order from range to act to record is the order of precedence that the second axiom of the Immanent Metaphysics states, and in physics the collection reads that order as the direction of time (Incommensuration, Chapter 8, Section X). The second axiom is the directed cycle of the three roles of comparison (the immanent, the omniscient and the transcendent, which Section VI describes), and *An Immanent Metaphysics* states the second axiom in aphorism 1.3-1. The cycle is an order of precedence, which says what comes before what, and not an order of clock time. At each step the cycle converges from many to one, as the many results that were possible narrow to the one result that is recorded. The direction of time is present in every act of comparison. So no physicist has to select an evolution by hand, as Prigogine's group selected the semigroup that runs toward equilibrium in the future. Prigogine looked for the arrow of time in the laws, because the laws were where physics kept its foundations, while the collection finds the arrow of time in the act of comparison through which every law is learned.

The collection also keeps a second arrow of time, the entropic arrow. The physicist Ludwig Boltzmann explained the entropic arrow by counting the arrangements of the parts of large systems. Measurement, Chapter 12, Section VII, sets the two arrows side by side. Chapter 12 says that the structural arrow "is present in every single comparison". The structural arrow also "needs no large number of parts and no particular beginning of the world". The entropic arrow, the growth of entropy, "is a statistical arrow: it is found in systems of very many parts, and it needs a beginning of low entropy from which the growth proceeds". Chapter 12 states that "The two arrows point the same way wherever both are found", because "a record is itself an irreversible change", and "each act of recording joins the two arrows in one event". The joining of the two arrows holds down to the level of particles: "the arrow of the count is the order in which every trace follows the act that makes it, counted over very many particles" (The Matter We Know, Volume Two, Chapter 2, Section VI).

The distinction between the two arrows settles a dispute that ran through the last decades of Prigogine's life. Prigogine's critics agreed with Boltzmann that counting states and a beginning of low entropy explain the irreversibility of large systems. The critics saw no need to change the dynamics. The physicist Jean Bricmont (1996) was among the clearest of the critics. Prigogine held that irreversibility is more than statistics and must be found at the level of the fundamental description. Each side was right about one arrow. The entropic arrow is statistical and needs its low-entropy beginning, as the physicists who follow Boltzmann say. The structural arrow lies beneath the entropic arrow, and the structural arrow holds in a single comparison and needs no special beginning. Prigogine said that an arrow of time must exist at the level of the fundamental description. The structural arrow lies in the impossibility of faithful reversal, which holds for one particle as for many. The structural arrow needs no modified law.

## V. Instability, Amplification and Hard Randomness

Prigogine's technical work showed that in unstable systems the description by trajectories cannot be carried forward in time, and that ensembles, which are distributions of probability, describe what trajectories cannot describe. The collection agrees with Prigogine about the unstable systems, but the collection finds the source of the openness of the future in a different place: at the edge of the domain of measurement.

Measurement, Chapter 12, Section VI, describes the mechanism by which small differences grow. Chapter 12 calls the mechanism *microstate amplification*: "the process by which small differences at a fine-grained level of a system are propagated and magnified into differences at the level that matters for the system's behavior". Section VI separates complex systems from systems that are merely complicated. Section VI gives two examples: "A clockwork is complicated: it has many parts, and a small error in one gear stays a small error in the time it shows. The weather is

complex". A small difference in the weather grows into a large difference, while a small error in a clockwork stays small. Section VI concludes: "So a complex system carries, at the level of its behavior, the asymmetry of its finest differences, and no symmetric description of finite resolution contains it". A description of finite resolution is a description that records differences only down to some smallest size. Section VI states Prigogine's finding about unstable systems without Prigogine's mathematical formalism.

Where do the finest differences in a complex system come from? The Basis of Physics, Essay 6, Section VI, follows the amplification downward through two examples: the three-body problem, which is the motion of three bodies that pull on one another by gravitation, and the weather. Essay 6 states that the differences that decide the outcome "fall below the limits of measurement, below the microscopic limit, where differences inside one cell of the space of states are not distinct states. At that point the microstate of the system cannot be known, not because our instruments are poor but because there is no instrument for it. And yet the system still produces an outcome". In the quotation, the space of states is the set of all the states the system could be in. The microstate is the exact state of every small part of the system. What produces the outcome is "whatever is happening at the scale below the boundary of measurement", and what happens below the boundary, in the words of Essay 6, "from the standpoint of anything inside the domain, is hard random". Essay 6 therefore draws the picture "of a world in which the incompressible residue is not confined to the laboratory but seeps upward through every process that amplifies what it cannot resolve". In the picture of Essay 6, the incompressible residue is the hard randomness below the boundary of measurement.

Prigogine and the collection differ about where chance comes from. Prigogine placed chance in the law. The dynamics of a large Poincaré system has an irreducible representation by ensembles, a description by ensembles that cannot be reduced to trajectories, so for Prigogine probability is part of the fundamental description. The collection places chance at the edge of the domain of comparison, which is also the domain of measure-

ment. The edge lies below the action that Planck's constant marks, where no measurement can be made (The Basis of Physics, Essay 6, Section VII), and amplification carries chance upward from the edge. Action is a quantity of energy multiplied by a time. Planck's constant is the constant of quantum physics that marks the scale of action below which no measurement can be made. A stochastic model is a mathematical model that contains probabilities for its outcomes. The difference between the two placements matters, because a stochastic model cannot contain newness either. Measurement, Chapter 12, Section V, states the reason exactly: "A stochastic model does not escape this: a mathematical description exists as structure, laid out whole, and any randomness in it is a distribution laid out in advance; the one outcome that occurs is a finding, and no structure laid out in advance contains it". A law of probabilities is still a law, however irreducible the law is: a structure laid out in advance and the same from every standpoint. Prigogine's laws "of possibilities" therefore stop one step short of what he wanted. The missing step is the step from the distribution to the one outcome that occurs. The newness that Prigogine looked for is in the outcome, and the outcome is a finding, made in an act of comparison, while the distribution is laid out in advance and so cannot contain the outcome. Bishop observes that the trajectories remain valid locally even where the ensembles are needed globally. Bishop's observation fits the collection's account: determinate structure is present to some degree in every world and complete in none, which is the non-polarization principle again (Causality Without Determinism, Chapter 1, Section IX).

## VI. Order Out of Chaos

Prigogine's dissipative structures show order built by irreversible processes. Near equilibrium, order is of the kind that The Matter We Know, Volume Two, Chapter 2, Section XIV, sets out: a system held at a fixed temperature "settles where its energy, less its temperature times its en-

tropy, is least". When the system is cold, the system settles into bonded, aligned or packed arrangements. Far from equilibrium, a flow of energy can keep a pattern in being that a system at equilibrium would never have, such as the hexagonal cells of a fluid heated from below. At a point where several patterns become possible, the system takes one of the patterns. Prigogine called the process order through fluctuations: a fluctuation too small to be seen decides which pattern appears.

The collection says what decides the fluctuation. At a branching point the system is complex in exactly the sense of Section V: the outcome depends on differences that, when followed downward, pass below the microscopic limit, and below the microscopic limit the outcome is hard random. So the pattern that appears is new in the full sense. The event itself settles which branch the system takes, and no law laid out in advance settles the branch. Once the system has taken the branch, everything that follows on the branch is lawful.

The collection describes every event in three aspects (change, causality and choice), and the three aspects say in what order the new pattern arrives. Causality Without Determinism, Chapter 6, Section II, following *An Immanent Metaphysics*, pairs each of the three aspects with a modality. Change is the immanent, "the continuity of content and asymmetry of context". Causality is the omniscient, which "registers what is conserved". Choice is the transcendent, "what introduces the new into the domain". The immanent, the omniscient and the transcendent are the modalities of *An Immanent Metaphysics*, the three roles of comparison. The immanent is held in the act, and the omniscient is held as structure laid out. The transcendent is implicit, held in the stance. In the collection, the content of a comparison is what is found, and the context is the setting in which the content is found. The stance is the side from which a comparison is made. In the terms of physics, change is what continues and causality is what is conserved and can be traced. Choice is what enters new. In a cell of heated fluid, the three aspects come in a fixed order: choice first, then change, then causality. The new pattern enters at the branching point as choice, and the new pattern unfolds as change. Afterward, anyone who studies

the pattern reads the pattern as a causal history. Prigogine wrote of the creativity of nature. The collection, for its part, places the new in every act, at every scale, in a proportion that varies with the scale (Causality Without Determinism, Chapter 6, Section IV). At the branching points of a system far from equilibrium, the newness of every act is amplified to a size that anyone can watch.

Appendix D is the register that sets Prigogine's expectations beside the sealed record. Appendix D states that the two accounts "agree on what the world will show about time and chance", and that no measurement named in this chapter or in the books of the collection separates the two accounts. Appendix D records two agreements: the first agreement is that no world is deterministic and the arrow of time is real. The sealed record registers the two claims together as Prediction 28, and the measured violations of time reversal agree with Prediction 28. The second agreement is that the pattern a system takes at a branching point far from equilibrium is not fixed in advance. Only this chapter states the second agreement, which is not among the predictions of the sealed record. In experiments on the crystallization of sodium chlorate, crystals grown from a solution of the salt come out left-handed or right-handed. The results of the experiments are consistent with the second agreement. So no measurement decides between Prigogine's account and the collection. The two accounts part, as Sections IV and V set out, on where the arrow of time and chance are found: Prigogine finds both in the laws, while the collection finds the arrow in the act of comparison and finds chance at the edge of the domain of measurement.

## VII. Summary

Ilya Prigogine established four conclusions against the settled view of his time. He established that the arrow of time is real and that irreversible processes build order. He also established that chance cannot be removed from unstable systems, and that determinism fails. The physics collection

holds each of the four conclusions and gives all four one ground, the Incommensuration Theorem. Determinism is the assertion of total symmetry and total continuity together, the first pairing that the Incommensuration Theorem forbids. So no world is purely deterministic, whether the world is stable or unstable. The arrow of time lies beneath the laws, and no modified law is needed for the arrow: symmetric laws guarantee lawful reversal and never guarantee faithful reversal, and the direction of time is the direction in which comparison proceeds. The statistical arrow of Boltzmann rests on the structural arrow and joins the structural arrow in every record, because every record is itself an irreversible change, and so each side of the old dispute keeps the arrow that the side was right about. Chance has its source at the edge of the domain of measurement, and every complex process amplifies chance upward. A law of probabilities remains a law laid out in advance, and the newness is in the finding. Prigogine's order through fluctuations is the newness of a finding, made large at a branching point. Prigogine looked in the mathematics of unstable systems for what the collection finds in the structure of the act of comparison. Every law is known through the act of comparison. Order made by flows of energy raises the next question, which is what makes a living system more than a structure far from equilibrium. The biologist Robert Rosen took up the question, and the next chapter sets Rosen's account beside the collection.

**Key Concepts**

- Determinism is total symmetry with total continuity, the first pairing that the Incommensuration Theorem forbids. So no world is purely deterministic, whether the dynamics of the world are stable or not.
- The failure of determinism leaves causation: continuity with asymmetry, a pairing that the Incommensuration Theorem allows.
- Lawful reversal and faithful reversal: symmetric laws guarantee lawful reversal and never guarantee faithful reversal.
- Two arrows of time: the structural arrow, present in every comparison, and the entropic arrow, which is statistical and needs a beginning of low entropy; the two arrows join in every record.
- Microstate amplification carries hard randomness from below the edge of measurement into behavior at every scale.
- A law of probabilities is still structure laid out in advance, and the newness is in the outcome, which is a finding.
- Order through fluctuations is newness amplified at a branching point.

## Terms

**Dissipative structure.** An ordered pattern maintained by a continuing flow of energy and matter far from equilibrium.

**Faithful reversal.** A reversal that retraces exactly the states the original process passed through and arrives at exactly the original condition.

**Hard randomness.** An outcome that no prior specification fixes, however complete; no capacity for causal prediction exists for the outcome.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Large Poincaré system.** In Prigogine's program, a dynamical system with a continuous set of resonances among its motions.

**Lawful reversal.** The property that the time reverse of a lawful process is itself lawful.

**Microstate amplification.** The magnification of small differences at a fine-grained level of a system into differences in the system's behavior.

**Modalities.** The three roles of comparison: the immanent (held in the act), the omniscient (held as structure laid out), the transcendent (implicit, held in the stance).

**Non-polarization principle.** Every world is to some degree causal, and no world is purely deterministic.

**Second axiom.** The directed cycle of the three roles of comparison, an order of precedence and not of clock time, converging from many to one at each step (*An Immanent Metaphysics*, aphorism 1.3-1).

**Structural arrow of time.** The direction in which comparison proceeds: from the range of what is possible, through the act, to the record.

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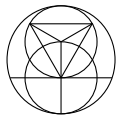

Robert Rosen

# No Largest Model

*Robert Rosen, Relational Biology and Physics from Comparison*

## Abstract

Robert Rosen (1934 to 1998) was a biologist who built a science of life on relation rather than on matter. Rosen set out the modeling relation, the relation between a natural system and a formal system (a piece of mathematics) that models it. He defined a mechanism as a system all of whose models can be simulated, that is, computed by a machine that follows a fixed procedure. A system is closed to efficient causation when every process that makes some part of the system is itself made within the system. In *Life Itself* (1991) Rosen argued that an organism is a material system closed to efficient causation, and that the models of an organism therefore cannot all be simulated by any machine. The physics collection of the Immanent Metaphysics is the set of books in which I set out physics from comparison, the act of telling two things apart. I call the physics collection the collection for short. On three points the views of the collection are closer to Rosen's views than to the views of almost any other scientist. The collection takes the relationship between things as more fundamental than the things related. It holds that a model, however well it fits, is not the thing it describes. And the collection holds that a computation cannot be what a self is, where a self is choice gathered, held together and carried forward as one's own. The collection grounds each of the three points in the structure of comparison. From that ground I derive two res-

ults that go beyond Rosen. The first result is that every comparison leaves a remainder that no rendering contains, so no natural system has a largest model. A rendering is a model or a description of a thing. The remainder is the part of the thing that a rendering approaches as closely as one wishes and does not contain. A largest model would be one model from which every other model of the system follows. Since a mechanism, in Rosen's strict sense, would have a largest model, "mechanism" in that sense names a property of descriptions and not of anything in nature. The second result is that what makes a living being different in kind is choice gathered into a self (brought together from many acts of comparison into one persisting stance) and known from inside. No description from outside can draw that difference. Rosen's closure to efficient causation is organization in the transcendent role: it is the condition from which a living being's activity proceeds. The autopoiesis of Maturana and Varela is organization in the transcendent role as well. Autopoiesis is a network of processes that continuously regenerates the network that produced it. Rosen's diagram of closure is a model, and the model cannot contain the organization it draws. In this chapter I also show how the long debate over Rosen's proof of non-computability bears on the collection's conclusion. I reach the conclusion that a living being is not a mechanism on two grounds of my own, and neither ground uses Rosen's proof, which is the step that the debate concerns.

## I. Relation Before Matter

Rosen trained under the biologist Nicolas Rashevsky at the University of Chicago, in the program Rashevsky called relational biology. The starting point of relational biology was that what makes a thing alive is how its parts are organized, and not the stuff it is made of: the same organization, realized in other stuff, would be the same kind of living thing. In 1958 Rosen gave that starting point its first exact form, the metabolism-repair systems, written (M,R) systems. An (M,R) system is an abstract diagram of components that make one another, in which the parts that carry out

metabolism are themselves replaced by repair processes that the system's own metabolism supplies. For the next forty years Rosen developed relational biology in category theory (a branch of mathematics that describes structures by the maps between them) and in a series of books. The main results of the program are in three of those books: *Anticipatory Systems* (1985), *Life Itself* (1991) and the posthumous *Essays on Life Itself* (2000).

Rosen's achievement is real, and it came early. Rosen saw that a living system is a closed web of relations and not a list of parts, and he saw it earlier than most workers in the life sciences. He gave that web of relations an exact mathematical description. He saw that the question "what is life?" is a question about organization, and that physics, as practiced, had no way to ask that question. And he saw that a modeler who takes a living system apart into components and rebuilds it as a machine, by the habits of modeling that serve physics so well, loses exactly what makes the system alive. Rosen's question was whether a natural system can be captured whole by a model, that is, described completely by one model. The question is about every natural system, and so it belongs in a book of models of the universe. The collection answers Rosen's question for physics as well as for life.

The collection starts where Rosen starts, with relation put first, but the collection grounds that start in the act of comparison rather than in biology. I state the starting point in The Last Turtle, Chapter 1, Section VI:

> "we take the relationship between context and content as more fundamental than the context or the content, and we define each of them in terms of that relationship".

The sentence from The Last Turtle is the ground of the first axiom of the Immanent Metaphysics. The immanent, the omniscient and the transcendent are the three roles of comparison. The first axiom says that the immanent, the act of relating as it happens, is more fundamental than the omniscient (what is laid out as structure) and the transcendent (the stance and

the range of possibility an act proceeds from). The collection's single premise, the *Root Tautology*, says that comparison, interaction and relation are one act under three names (The Grand Synthesis, Chapter 1). Rosen put relation before matter in biology. The collection puts relation, the act of comparing, before everything, matter included. So when Rosen put relation before matter in biology, he gave one case of the collection's ordering. Rosen's nearest predecessor in putting relation first is the philosopher Charles Sanders Peirce. I write in Peirce and the Immanent Metaphysics, Chapter 1, that Peirce "held a version of the first axiom, in his insistence that relation is irreducible".

A science built on relation must answer the oldest objection to relation, the regress of the philosopher F. H. Bradley. Bradley argued that a relation joining two terms needs a further relation to join the first relation to each of the terms, and so on without end. I answer Bradley in The Ground of Objection, T1.1a, my book on the objections of earlier philosophy, and in that answer I give relational biology the ground that relational biology lacked:

> "a comparison is not an object standing between its terms. It is the boundary at which they are told apart, and a boundary has no interior. Its entire being is the distinguishing it performs".

The relation is the relating, not a thing that relates. Rosen needed the answer of T1.1a and did not state it: the organization of an organism is the parts relating to one another, and not one more part standing beside them.

## II. The Modeling Relation

Rosen's best-known device is the modeling relation. A natural system has its own causal order: one state of it brings about the next. A formal system, a piece of mathematics, has its own order of inference: one statement entails the next. To model the natural system is to encode its states as

statements, let the formal system run, and decode the result back into a prediction about the world. So there are two routes from a present state to a later one: the route of encoding, inferring and decoding, and the route of letting nature run. A model succeeds when the two routes agree, that is, when encoding, inferring and decoding gives the same state as letting nature run. Rosen insisted that the encoding and the decoding belong to neither system. The encoding and the decoding are a third thing, a relation made by someone, and nothing in the formal system can supply them.

The collection describes the same relation, and it names exactly the two things that the relation joins: a model and the reality the model describes. I write in Causality Without Determinism, Chapter 4, Section I: "Compatibility between a model and a body of measurements is not equivalence: many models may be compatible with the same data, and no amount of compatibility can establish that the model is the reality it describes". My book Incommensuration states the difference between a law and a measurement in one sentence: "A law exists; a measurement is real" (Incommensuration, Chapter 3). The collection calls the step of encoding and decoding an *identification*, made in the first person and in the open: the one who makes the step states the step, together with the observation that bears on the step. I say what an identification is in Measurement, Chapter 6, Section III:

> "An identification is the place where an argument meets the world, and so it is the place where soundness is decided. Within a structure fixed by definition, a deduction is valid, and it is certain. Its passage to the world carries a reading, because the structure and the world are two domains".

Rosen draws the modeling relation as a commuting diagram: two routes, nature's and the model's, that must arrive at the same state. Rosen's commuting diagram describes the same step as the collection's identification: the place where a formal structure is joined to the world by someone who

makes the join. The collection adds the reason why the join can never become part of the formal system. The reason is that mathematics deals in claims held as structure laid out, while the act of joining that structure to a world is held in the act itself (Physics Is Not Math, Chapter 9, Section III). The order of depth ranks four domains: metaphysics, then physics, then computation, then mathematics (Physics Is Not Math, Chapter 5). The formal system comes after the act that encodes into it, by the order of depth. Rosen's encoding and decoding are not part of the formal system, because they come before it.

## III. Mechanisms, and Why Nothing Has a Largest Model

In *Life Itself* Rosen drew the line between machines and organisms with the modeling relation. A natural system is a *mechanism* when every one of its models can be simulated, that is, computed by a machine that follows a fixed procedure. For a mechanism the models can be gathered into one largest model, from which every other model follows. A modeler loses nothing by taking a mechanism apart into components: the analysis and the rebuilding agree. Rosen called a system that is not a mechanism *complex*. Rosen's central claim is that an organism is complex. In Rosen's definition, an organism is a material system closed to efficient causation: every process that makes some part of it (every efficient cause, in Aristotle's term) is itself made by some other process within the system. Closure to efficient causation folds the system back on itself, because the makers of the parts are themselves made within the system, and so a description of the system must refer to the system itself. Rosen argued that this self-reference cannot be captured in any model that a machine can simulate.

I derive Rosen's distinction from the structure of comparison, and I find that the distinction applies more widely than Rosen applied it. I define what it is to be classical in Causality Without Determinism, Chapter 5, Section II, in terms Rosen would recognize:

> "A classical system is one that can be virtualized, and that is the single defining feature of being classical: classical things are modelable. If a model of a thing can be built that behaves identically to the original for all purposes one cares about, then that thing is classical".

The same section of Causality Without Determinism says why a model works at all: "Any form of modeling inherently depends on symmetry: to model a thing is to treat some of its aspects as irrelevant to the behavior of interest, and to factor them out as not important". A modeler holds the differences of context that the model leaves out to be differences that make no difference. To treat those differences so is a choice of purpose, and the definition of classical carries the choice in its words "for all purposes one cares about".

Rosen's mechanism is the collection's definition of classical with the purposes removed: a system with a model that serves every purpose at once. If every other model of a system follows from one model, that one model must leave out no difference that any purpose could need, and so it must contain the whole of what it models. The collection shows that no natural system has a model that serves every purpose at once. The ground is the Incommensuration Theorem, which states that symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The Incommensuration Theorem is a structural fact about the nature of knowing. I formulated the first axiom of the Immanent Metaphysics in or before 1991. I formulated the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996. I did most of my physics work in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the

Incommensuration Theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1. A model is laid-out structure, invariant from copy to copy: symmetry perfected. If a model contained the whole of what it models, the model would also be in unbroken contact with all of it: continuity perfected. The model would therefore pair perfected symmetry with perfected continuity, and that pairing is the first of the two pairings the Incommensuration Theorem forbids. So every rendering "leaves a remainder", in the words of Physics Is Not Math, Chapter 21, Section V, and the remainder is "the part of what is rendered that a rendering approaches as closely as one wishes and does not contain". I give the same result in the terms of the three roles of comparison in The Last Turtle, Chapter 3, Section XIII: "the omniscient cannot contain the transcendent".

Every interaction is a comparison, by the Root Tautology, and every comparison leaves a remainder in a second sense: an outcome that nothing prior fixes, which the collection calls hard randomness (Causality Without Determinism, Chapter 5, Section IV). The two remainders are one: what no rendering of a comparison contains is exactly the outcome that nothing before the comparison fixes. So no natural system, organism or stone, has a largest model. I state the consequence in so many words in The Ground of Objection, T2.18: "A description is a comparison; therefore no description of any actual thing is complete, and this is a theorem the system derives and builds on rather than a limitation it concedes". What Rosen called a mechanism is a property of a description: a system described for a purpose for which what the description leaves out makes no difference. A clock is a mechanism for the purpose of telling time and not for the purpose of predicting each collision of its atoms. The collection affirms that living things have mechanisms. I hold in The Ground of Objection, T2.24, that the deepest claim of the collection, the Root Tautology, entails those mechanisms. The argument of T2.24 is that an organism telling two things apart is interacting, "so the system's deepest claim entails that there are comparings going on inside an organism that compares, that they are made of something, and that what they are made of can be described". A description of those mechanisms is a description within a do-

main, and neither that description nor the collection's account of comparison displaces the other. Only one step fails: the step from "this organism has mechanisms that can be described" to "this organism is a mechanism", which is the step to a largest model. Rosen drew the line between mechanism and organism inside nature. The collection draws the line of mechanism between the description and the thing described. Inside nature the collection finds a different line, the gathering of choice into a self, which Section VI of this chapter sets out.

## IV. The Debate over the Proof

Rosen claimed that closure to efficient causation forbids models that a machine can simulate. His claim rests on a proof in the mathematics of categories, and the proof has been disputed. In 2006 Dominique Chu and Weng Kin Ho reviewed the proof in the journal *Artificial Life*. They argued that some central notions of the proof are not well defined, and they concluded that the proof does not hold. Aloisius Louie was Rosen's student and the chief interpreter of his work. In 2007 Louie replied in the same journal that a living system must have models that cannot be computed. Chu and Ho answered Louie in turn. In 2009 Matteo Mossio, Giuseppe Longo and John Stewart gave an expression of closure to efficient causation in the lambda calculus, a formalism of computation. They argued that closure to efficient causation does not by itself rule out computable models.

I reach my conclusion on grounds of my own, and those grounds do not use the step of Rosen's proof that the debate concerns. My conclusion is Rosen's, that a living being is not a mechanism, and more besides. I reach it on two grounds already set out, each with its own conclusion. The first ground is that every natural system leaves a remainder that no model contains (Section III), so no natural system, the living included, has a largest model, and none is a mechanism. The second ground is that a computation lacks the bound triple of arrow, hard randomness and the

subjective, which a self has (Section VI), so no computation is a self, and no simulation of a living being is what that being is. In the bound triple, the arrow is the arrow of time, and the arrow of time, hard randomness and the subjective are distinct but cannot be separated. Neither ground uses Rosen's categorical proof. So however the debate is settled, the settlement does not change the collection's conclusion. The debate bears on one formal argument for Rosen's conclusion, and the collection reaches that conclusion on other grounds.

The collection also says what kind of question is at issue in the debate. Whether closure to efficient causation, written as a formal property of a diagram, forces a non-computable model is a question of mathematics, settled by proof. Whether a living being is a mechanism is a question about the world, and the formal property is a rendering of the closure in the living being. The order of depth puts mathematics after physics. So a rendering cannot set the scope of the thing that the rendering renders: what a diagram can or cannot do does not decide what the organism can or cannot be. Mossio, Longo and Stewart's computable expression shows that one rendering of closure can be computed. Their result holds of the rendering only, because that rendering, like every other, leaves its remainder. So the expression does not show that the organism so rendered can be computed.

## V. Closure, and the Foundation That Describes Itself

Rosen found that the central feature of life is a loop: a system whose making refers back to itself. Because the making of a looped system refers back to the system itself, a description of the system is impredicative: the description defines a thing in terms of a whole to which the thing belongs. Rosen took a loop of self-making to mark the living off from the mechanical. He saw that mathematics built from the bottom up, element before set, has trouble expressing a loop of self-making, because that mathematics defines each element before any set that contains it.

I find a closure of the same kind as Rosen's loops at the foundation of the collection, and I find it in every act, not only in organisms. The Root Tautology is a loop: every interaction is a comparison, every comparison a relation, and every relation an interaction, and none is first. The second axiom orders the three roles of comparison in a cycle with no first member. And the axioms, taken as their own subject matter, describe themselves. I state the closure of the axioms in full in The Last Turtle, Chapter 3, Section IX:

> "the axioms describing themselves is itself a process, an instance of the general class of process, and Axiom II is the axiom of process. So the axioms describe not only themselves but the process of describing themselves. That is full closure over the reification of the foundation".

I state the same closure as a property of the whole framework in The Grand Synthesis, Chapter 4, Section VI: the axioms, turned on themselves, describe their own structure with perfect fidelity.

The closure of the axioms is also my answer to the fear that self-reference must regress without end. I grant Bradley's regress in The Ground of Objection, T1.1a, and I show the shape of the regress. Each step of the regress treats a relation as a term, and "three such levels (relation, domain, identity) form a closed cycle: each becomes the next, and the third returns to the first. The ascent Bradley describes is real, and it is periodic rather than infinite". A loop of exactly three steps is impredicative in Rosen's sense and stable at once: after the third step the regress returns to its first level. I say what kind of closure the foundation claims in The Ground of Objection, T2.18: "The closure claimed is a closure of the descriptive apparatus and not of the inquiry". Rosen's organism is closed in the same way: closed in its making, open in its encounter with everything it meets.

Rosen found closure to efficient causation in the living cell. The collection finds closure of the same form in the act of comparison itself, beneath every domain, and so the collection can say why closure appears in the

living. In a living being, the closure present in every act of comparison is gathered by one self, which keeps making itself from what it has done. Rosen's impredicative loops are the closure of the foundation, present in every act, as that closure appears in the living. The loops are not an anomaly that biology adds to physics.

## VI. What Makes a Living Thing Different

Rosen draws the line between organism and mechanism by a property of organization that is visible in a relational diagram: closure to efficient causation. The collection agrees that a living being is different in kind from a stone, and it places the difference in something that no diagram can show. I set the difference out in Home in the World, "A Village That Is Alive". Every part of every world has some degree of choice, however small, and the degree of choice runs on without a break from the stone to the person.

> "The difference in kind lies elsewhere: in whether choice is gathered, held together and carried forward as one's own, and known from inside. A self is that gathering".

The same passage of Home in the World says why no description from outside can draw the line: "a true choice, seen from outside, looks exactly like chance, so no description from outside can draw the line".

The collection completes the case for the difference in kind with its account of why a computation is not a self. A classical computation is one rule applied the same way at every step, which is symmetry perfected. By the Incommensuration Theorem a classical computation is intrinsically discontinuous. The arrow of time in the first person is continuity with asymmetry, and the arrow cannot be composed of the steps of a computation. So a computation lacks the arrow of time, and it lacks hard randomness. Because the arrow, hard randomness and the subjective are bound

together, a computation lacks the subjective too: "classical computation, however intricately organized, cannot be what consciousness is" (Causality Without Determinism, Chapter 5, Section VI; the bound triple in Section III). I extend the result about computation to the simulation of a whole world in the same Chapter 5 of Causality Without Determinism. A deterministic simulation can match the statistics of the world's outcomes to any chosen precision and still cannot be what the world is, because the outcomes of the simulation are fixed by its program (Section VIII).

Rosen's closure is very like the autopoiesis of the biologists Humberto Maturana and Francisco Varela. Autopoiesis is a network of processes of production that continuously regenerates the very network that produced it. I take up the philosopher Evan Thompson's enactive account, which Thompson builds on autopoiesis, in The Immanent Metaphysics and the Modern Engagement, Chapter 9. There I assign the three parts of Thompson's account to the modalities, which are the three roles of comparison: "Thompson's autopoietic organization maps to the transcendent modality, his embodied living activity to the immanent, and his sense-making to the omniscient". In that chapter autopoietic organization is the transcendent because it is the condition of the living system, "the network of relations that defines what the system is prior to any particular instance". Rosen's closure to efficient causation is organization of the same kind as autopoietic organization, and it takes the same role. The transcendent is the organization of the organism, the condition from which its living proceeds. The immanent is the organism living in its surroundings, making and remaking itself. And the omniscient is Rosen's relational diagram of that organization, a model laid out as structure.

Once Rosen's closure is assigned to the transcendent, I can say exactly why Rosen's criterion picks out the living so well, and why the criterion cannot by itself draw the difference in kind. A being that gathers choice and carries it forward as its own must make and remake itself from within: what it is depends on what it has done, and what it does depends on what it is. When the organization of such a being is seen from outside and drawn as a diagram, the diagram shows a system whose every making is

made within the system, and that is closure to efficient causation. But the diagram is a laid-out structure, and the omniscient cannot contain the transcendent. So no diagram of closure contains the organization it renders, and still less does a diagram contain the self that gathers within that organization.

Chapter 9 of The Immanent Metaphysics and the Modern Engagement also names the one point on which the collection differs from enactivism, the school of Thompson's enactive account. The collection differs from Rosen on the same point: "the question of whether the modalities extend to non-living systems, which Thompson's framework does not affirm and the Immanent Metaphysics requires". I state the collection's side plainly in The Ground of Objection, T4.6: "There is no non-conscious interaction, and every interaction has a subjective aspect". Rosen and the enactivists draw a line between the living and the non-living by organization. The collection finds the relating, and some degree of choice, on both sides of that line, and it finds the difference in kind in the gathering of choice into a self.

## VII. Anticipation

In *Anticipatory Systems* Rosen described a kind of system that contains a predictive model of itself or of its surroundings. Rosen called a system of that kind anticipatory: the system changes its present state according to what its model predicts for a later time. Rosen held that anticipation of this kind is everywhere in living things, and that physics, whose causes run only from the past, had no room for anticipation.

The collection places anticipation in the cycle of every comparison. The second axiom orders the three roles of comparison in a cycle: from the stance to the act, from the act to the laid-out finding, and from the laid-out finding to a new stance (I set the cycle out in Measurement, Chapter 4, Section VIII). The record of what has been found shapes the range from which the next act proceeds. A model is a record laid out as structure. An

anticipatory system is a system in which the step from the laid-out finding to the new stance is carried by a model that the system holds of itself. The model is present in the system, and the model works by shaping the range of the present act, so no cause runs backward from the future. Rosen was right that the step from the laid-out finding to the new stance is everywhere in the living. The collection adds that the step is in every comparison. In a self, the step is carried by a model that the self holds of itself, and the self takes the step up as its own.

The sealed record is my numbered register of predictions. Appendix E is the register that sets Rosen's account beside the sealed record. In Appendix E I find that the sealed record "carries no prediction on which the two accounts give different results, and the relation essay states none". Appendix E records one agreement: an anticipatory system acts on a model it holds in the present and needs no signal from a later time. The sealed record registers that agreement, for every process, as Prediction 27. Only one prediction of the sealed record puts to a measurement the collection's claim that no natural system has a largest model: Prediction 29, which concerns a discrete rule offered as the foundation of physics. Rosen's account neither states nor denies Prediction 29. The remaining differences between the two accounts are claims of logical form, descriptions of what a thing is, or claims about the act of knowing, and no measurement decides them.

## VIII. Summary

Robert Rosen and the physics collection agree on three things. First, relation comes before the things related. Second, a model, however well it fits, is not the thing it models, and the join between the model and the thing is made by someone and belongs to neither. Third, a living being is not a mechanism. Rosen reached the three things as a biologist, with the modeling relation and the mathematics of categories. The collection derives the three from the structure of comparison, and from that ground the collec-

tion carries each of the three further than Rosen took it. Relation comes first because comparison, interaction and relation are one act. A model is not the thing it models because every rendering leaves a remainder, and so no natural system, living or not, has a largest model. Rosen's mechanism is therefore a property of descriptions. A living being is different in kind because choice is gathered in it into a self and known from inside, and no description from outside contains that gathering. Rosen's closure to efficient causation, like autopoiesis, is the organization from which that gathering proceeds. His diagram of the organization is a model, and the model cannot contain the organization. Where Rosen and the enactivists draw the line of life by organization, the collection finds the relating, and some degree of choice, on both sides of the line. The dispute over Rosen's proof concerns one formal argument for his conclusion, and the collection's conclusion rests on other grounds. Rosen saw the closure that is the central feature of life. The collection finds the same closure at the foundation of every act, and finds life to be the place where that closure is gathered. Rosen asked what makes a living thing more than a mechanism. In the next chapter the neuroscientist Giulio Tononi asks what makes a physical system conscious, and he answers with a quantity computed from the structure of the system's causes.

**Key Concepts**

- Rosen's modeling relation and the collection's identification describe one step: a formal structure joined to the world by someone who makes the join.
- A classical system is one that can be modeled for the purposes one cares about. No natural system can be modeled for every purpose at once, because every rendering leaves a remainder.
- Rosen's mechanism is a property of descriptions, not of anything in nature.
- The collection's conclusion that a living being is not a mechanism rests on two grounds of its own: every rendering leaves a remainder, and a computation lacks the bound triple. The conclusion uses none of Rosen's categorical proof, which is disputed.
- Closure to efficient causation appears at the foundation of every act, in the Root Tautology and in the axioms describing themselves, and life is where that closure is gathered.
- The difference in kind between the living and a stone is choice gathered into a self and known from inside. Every interaction has a subjective aspect, so the modalities apply to the non-living too.
- Rosen's closure, like autopoiesis, is organization in the transcendent role. Living activity is the immanent, and a model of the organization is the omniscient.
- A relation is the relating, not a further thing that relates. Bradley's regress is periodic, a closed cycle of three, and not infinite.
- Anticipation is the step from the laid-out finding to the new stance, carried by a model the system holds of itself.

## Terms

**Bound triple.** The arrow of time, hard randomness and the subjective, distinct, inseparable and not interchangeable; consciousness is the bound triple taken as one act.

**Gathered.** Said of choice: brought together from many acts of comparison into one persisting stance.

**Autopoiesis.** Maturana and Varela's term for a network of processes of production that continuously regenerates the network that produced it.

**Closure to efficient causation.** Rosen's defining property of an organism: every process that makes some part of the system is itself made within the system.

**Complex system.** In Rosen's usage, a natural system with at least one model that cannot be simulated.

**Hard randomness.** An outcome that no prior specification fixes, however complete; the remainder every comparison leaves.

**Identification.** A stated step from the structure of comparison to a physical quantity, made in the first person, with the observation that bears on it.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Mechanism.** In Rosen's usage, a natural system all of whose models can be simulated, so that they have a largest model.

**Modalities.** The three roles of comparison: the immanent (held in the act), the omniscient (held as structure laid out), the transcendent (the stance and the range of possibility).

**Modeling relation.** Rosen's account of a model: states of a natural system encoded into a formal system, inference run, and the result decoded into a prediction.

**Remainder.** The part of what is rendered that a rendering approaches as closely as one wishes and does not contain.

**Root Tautology.** Comparison, interaction and relation are one act under three names.

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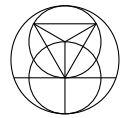

Giulio Tononi

# The Measure of an Inside

*Giulio Tononi's Integrated Information and Physics from Comparison*

## Abstract

The neuroscientist Giulio Tononi begins his Integrated Information Theory where few scientists begin a theory of consciousness: with experience itself. Tononi states his starting points as axioms, claims that he holds to be true of every experience. Tononi derives from the axioms a set of requirements on any physical system that has experience. He concludes that a system's experience is the system's intrinsic cause-effect structure, the whole structure of causes and effects that the system's parts specify upon the system itself. He calls the amount of that structure integrated information.

The Immanent Metaphysics is the philosophy that I set out in my book *An Immanent Metaphysics*. The physics collection of the Immanent Metaphysics is the set of books in which I set out physics from comparison, and I call the physics collection the collection for short. Integrated Information Theory has two consequences that the collection shares. A system that only passes signals forward has little or no consciousness, and neither does a conventional digital computer running any program whatever. On both accounts the reason is the same: what counts is the physical system's causal power upon itself, and not the computation that the system carries out. The collection derives both consequences from a ground of its own, the Incommensuration Theorem, by way of the bound

triple of the arrow of time, hard randomness and the subjective. The Incommensuration Theorem states that symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. Hard randomness is an outcome that no prior specification fixes, however complete. The subjective is the side from which a comparison is made. The arrow of time is the one direction in which every comparison proceeds. The arrow of time, hard randomness and the subjective are bound together so that no one of the three can be present without the other two, and Section III sets out the bound triple in full.

Integrated Information Theory agrees with the philosopher David Chalmers in its starting point and with the philosopher Daniel Dennett in its conclusion. The collection has already treated both philosophers. With Chalmers, Tononi takes experience as a real datum that no account of function, of what a system does, explains. With Dennett, Tononi ends by giving experience a complete third-person description, a description made from outside. Integrated Information Theory and the collection part at one step. Tononi's axioms are claims held in the act of experiencing. Tononi then identifies experience with a quantity computed from a system's structure, and a statement of that quantity is a claim held from outside. In the collection I hold that consciousness is the bound triple taken as one act. No quantity laid out from outside can be that act, because the Incommensuration Theorem keeps the subjective and the objective apart as two characters.

In this chapter I credit what Integrated Information Theory establishes. One thing the theory establishes is a candidate answer to a question that the collection asks: what measure of the richness and structure of a system's interactions tracks the system's degree of consciousness? I then set out where Integrated Information Theory and the collection agree, and I show exactly where and why the two accounts part. Last, the chapter answers the charge, made in 2023, that the theory is pseudoscience. The answer rests on the philosopher Karl Popper's own criterion for empirical science, as I read that criterion in my book *The Ground of Objection*.

## I. A Theory That Starts From Experience

Most scientific approaches to consciousness start from the brain and ask which activities of the brain go with reports of experience. Tononi started from the other end, from experience. In 2004 he proposed that consciousness is integrated information. Over the next two decades Tononi built the proposal into a theory, working with his colleagues Christof Koch, Larissa Albantakis and many others. Tononi and his colleagues published the current form of the theory, Integrated Information Theory 4.0, in 2023. Tononi and Koch state their method plainly: "start from consciousness itself, by identifying its essential properties", and only then ask what physical mechanisms could account for those properties. A system's causal power upon itself is what the system's parts, in their present state, specify about the system's own past and future states. Integrated Information Theory belongs in a book of models of the universe because Tononi places consciousness in a physical system's causal power upon itself, and so the theory makes a claim about what physical systems are.

Tononi states the starting points of the theory as axioms of experience. The 2023 statement of the theory gives a zeroth axiom, existence, and five further axioms: existence ("Experience exists: there is something"); intrinsicality ("Experience is intrinsic: it exists for itself"); information ("Experience is specific: it is the way it is"); integration ("Experience is unitary: it is a whole, irreducible to separate experiences"); exclusion ("Experience is definite: it is this whole"); and composition ("Experience is structured: it is composed of distinctions and the relations that bind them together"). Tononi translates each axiom into a postulate, a requirement on the physical system that has the experience. The first postulate sets the terms of all the rest: "The substrate of consciousness must have cause–effect power". The substrate, in that postulate, is the physical system that has the experience. A system's *integrated information* is then a measure of how far the system's cause-effect power upon itself cannot be reduced to the cause-effect power of its parts. The system's maximally irreducible core is the part of the system whose cause-effect power upon itself is the

least reducible to that of its parts. Tononi identifies a system's experience with the full structure of causes and effects that the system's maximally irreducible core specifies.

The books of the collection do not discuss Tononi by name, so I build the comparison in this chapter from three sources. The first source is what the collection's books say about consciousness, computation, measurement and the subjective. The second source is the chapters on David Chalmers and Daniel Dennett in my book *The Immanent Metaphysics and the Modern Engagement*, because Integrated Information Theory begins where Chalmers begins and ends where Dennett ends (Section IV). The third source is my book *The Ground of Objection*. I find more agreement between Integrated Information Theory and the collection than the vocabulary of either account would suggest.

## II. What the Collection Credits

The first axiom of Integrated Information Theory is a claim of the kind that the collection holds to be deepest. Physics Is Not Math, Chapter 9, Section III, distinguishes three ways in which a claim can be held. A claim is *performed* when the claim is established by what happens in the act of engaging it, including the act of trying to deny it: "To doubt that one is doubting is to doubt". A claim is *surveyed* when the claim is established from a vantage that holds many cases in view at once, by counting or by proving. A claim is *implied* when the claim is held without being stated, in the stance from which a practice proceeds. "Experience exists: there is something" is a performed claim, because anyone who denies the claim has the experience of denying it. Tononi made the decision to begin a science of consciousness from a performed claim, and not from a correlation surveyed in brain scans. The collection makes the same decision for every science. Tononi deserves full credit for making the decision inside neuroscience, where starting from experience runs against the usual practice of the field.

The second axiom, intrinsicality, names the subjective. Tononi's words "It exists for itself" mean that experience is had from a side, the side from which experience occurs. The collection calls the side from which experience occurs the subjective: the stance of the one to whom things happen (Causality Without Determinism, Chapter 5, Section III).

The most quoted consequence of Integrated Information Theory is also a consequence that the collection draws. A feedforward network is a network whose signals pass only from input toward output, with no part acting back on another. On Integrated Information Theory, a feedforward network has no cause-effect power upon itself, and so the network has no integrated information. Tononi and Koch call feedforward networks "zombies, carrying out tasks unconsciously", and they hold that a feedforward system matching a human brain's behavior exactly would be a perfect zombie. On the theory, a simulation of a brain on a digital computer has no more consciousness than the feedforward system has, because "the brain is real, but a simulation of a brain is virtual". What counts, for Tononi and Koch, is the causal power of the physical system, and not the program that the system runs. For the same reason, Tononi and Koch reject any behavioral test for consciousness. Causality Without Determinism, Chapter 5, Section VII, states the same conclusion in nearly the same terms: "Whether a system has the bound triple depends on whether it is a physical process making comparisons in the world, with an inside; it never depends on which program it runs". An inside, in the collection, is a subjective side from which a system's comparisons are made. Section IX of Chapter 5 of Causality Without Determinism asks a question about behavior: how could anyone tell a perfect imitation from a person? In Causality Without Determinism, Chapter 5, Section IX, I answer: "Not by watching the behavior, and the argument does not ask anyone to. It concerns what a computation is ... and that is known from how the computation is built, not from how it behaves".

Integrated Information Theory and the collection agree about which zombies can exist and which cannot. Chalmers' zombie is a being physically identical to a person, in every atom, but with no experience. On Integ-

rated Information Theory, Chalmers' zombie cannot exist, because the same physical causal structure has the same integrated information. The collection's reason rests on Axiom III, the third axiom of the Immanent Metaphysics. Axiom III holds the three roles of every comparison, which Section III names, to be distinct, inseparable and not interchangeable. The Modern Engagement, Chapter 8, gives the reason: "The zombie scenario is a request to separate the objective pole of comparison from the subjective pole, which Axiom III forbids", so that "the conception fails at a level deeper than physical law". Both accounts allow the other kind of duplicate: a different physical system that matches a person's behavior. In Integrated Information Theory the behavioral duplicate is the perfect feedforward zombie. In the collection the behavioral duplicate is a program that "may be capable of much else, including behavior that looks, from a third-person vantage, indistinguishable from conscious behavior" and still not be what consciousness is (Causality Without Determinism, Chapter 5, Section VI).

Integrated Information Theory and the collection agree on more than which systems lack consciousness: they also agree on where consciousness is. Integrated Information Theory locates consciousness in a system's causal power upon itself. In the collection, the Root Tautology is the identity of interaction, comparison and relation: the three are one act under three names. So, in the collection's terms, a system's causal power upon itself is the comparisons that the system makes within itself. Both accounts therefore put consciousness in the physical process, in what the system does with itself, and neither account puts consciousness in a description of the process. Among the scientific theories of consciousness, Integrated Information Theory comes nearest to the collection's account. Tononi reached his theory from experience, as I reached the collection's account from experience.

## III. The Collection's Account

The collection's account of consciousness rests on the Incommensuration Theorem: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. Symmetry is a sameness that holds across a change, as one law holds at every place and every time. Continuity is a connection without a break. The Incommensuration Theorem is a structural fact about the nature of knowing. I formulated the first axiom of the Immanent Metaphysics in or before 1991. I formulated the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996, and I did most of my work in physics in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1. Every comparison leaves a remainder, because symmetry and continuity cannot both be perfected. The remainder is an outcome that no prior specification fixes, however complete, and the collection calls the remainder *hard randomness*. Every comparison is made from a side, and the collection calls that side the subjective. Every comparison also proceeds in one direction, from the act of comparing to the record of the act, and the collection calls that direction the arrow of time. Causality Without Determinism, Chapter 5, Section IV, quotes Incommensuration, Chapter 8, Section X, on how the arrow of time, the subjective and hard randomness are joined: "These three are bound together as three aspects of the same structural act: comparison proceeding in a direction, registered by a perspective, with an outcome not fully determined. No one of the three can be present without the other two". The *bound triple* is the arrow of time, the subjective and hard randomness, bound together as three aspects of one act. Immanent, in the collection, means held in the act, as the act happens. Section III of Chapter 5 of Causality Without Determinism takes the bound triple as one act and states: "taken that way, the bound triple can be identified directly as consciousness, and it is immanent". The Modern Engagement, Chapter 7, Section V, states the same identification starting from the act of interaction: "Con-

sciousness is interaction. Not produced by interaction, not correlated with interaction, not supervening on interaction. Consciousness is the immanent modality, and the immanent modality is what interaction means". The modalities of the Immanent Metaphysics are the three roles of comparison: the immanent is held in the act, the omniscient is held as structure laid out, and the transcendent is implicit, held in the stance. The perceiver, the perceived and perception form a triple, and each member of the triple has one of the three modalities. The perceiver is transcendent, the perceived is omniscient, and perception, which is consciousness itself, is immanent.

A classical computation lacks all three members of the bound triple. A classical computation is "one rule applied the same way at every step" (Section VI of Chapter 5 of Causality Without Determinism). One rule applied the same way at every step is symmetry perfected. By the Incommensuration Theorem, whatever is absolutely symmetric is discontinuous in its own nature, and "one cannot compose a continuity out of purely symmetric components". So a computation has an indexing of its states, a numbering of the states in their order, and no arrow of time. A computation is fixed by its rule, so the computation has no hard randomness of its own. The computation then lacks the subjective as well, because no member of the bound triple can be present without the other two. Section VI of Chapter 5 concludes: "Classical computation, however intricately organized, cannot be what consciousness is". Hard randomness is choice when hard randomness is described from the position of the one engaged in the comparison. In Causality Without Determinism, Chapter 5, Section V, I put the two descriptions, from outside and from inside, in one line: "From outside, randomness; from inside, choice; one event, two descriptions, both correct, neither complete". Causality Without Determinism, Chapter 2, Section IX, puts the definition of consciousness in *An Immanent Metaphysics* into plain words: consciousness "is everything one perceives, taken together; it is where one's choices gather; and it is made of interacting and creating, not of a thing that exists apart".

## IV. Where the Two Part

Integrated Information Theory and the collection part at one step: the step from Tononi's axioms to his measure, integrated information. Tononi's axioms are performed claims, held in the act of experiencing. His postulates restate the axioms as properties of a physical system described from outside: the system's states, the system's transition probabilities (the probability of each next state given each present state), and the causes and effects that each part of the system specifies. Integrated information is computed from the description made from outside, and Tononi identifies the experience with the cause-effect structure that the computation returns. When a system is said to have a given amount of integrated information, the claim is a surveyed claim, because the claim is established from a vantage that holds all of the system's states in view at once. Establishing surveyed claims is what mathematics does best. So Tononi passes from performed claims to a surveyed claim, and then he sets the surveyed quantity equal to the performed act of experiencing.

Tononi passes from performed axioms to a surveyed quantity, and so Integrated Information Theory begins at the position of Chalmers and ends at the position of Dennett, two positions that the collection has already examined. Chalmers held that a complete functional account of the brain, an account of everything the brain does, would leave something unexplained. The collection agrees with Chalmers: "Chalmers' philosophical intuition and the theorem's structural result converge on the same claim" (The Modern Engagement, Chapter 7, Section IX). Tononi starts where Chalmers starts: experience is the datum, and an account of function does not capture experience. Dennett held that third-person description is complete. The collection names Dennett's position "a one-modality metaphysics operating in a three-modality world", and the collection calls the error of that position omniscient modal bias (The Modern Engagement, Chapter 8). Omniscient modal bias is the error of treating the omniscient modality, structure laid out from outside, as if it were the only modality. Tononi ends where Dennett ends: Tononi replaces Dennett's func-

tional description with a description of causal structure, but Tononi's description is still third-person, and Tononi says that the description is the experience. So Integrated Information Theory is the nearest of the scientific theories to the collection because the theory begins where Chalmers began, and the theory parts from the collection because it ends where Dennett ended.

The collection holds that the Incommensuration Theorem forbids the passage between the two kinds of claim in either direction, from the performed to the surveyed or from the surveyed to the performed. I set out the two characters that the theorem allows, the objective and the subjective, in my book The Last Turtle, Chapter 2, Section VIII: "Objectivity has its basis in symmetry, and subjectivity has its basis in continuity", and "The subjective, the side from which every comparison is made, is continuous and asymmetric: the stance persists without a break, and what it meets never exactly repeats". A quantity computed from a system's structure has the objective character: the quantity is exact, repeatable, and the same for every observer who computes it. The subjective is the other character. If a description captured the subjective completely in objective terms, the description would perfect symmetry and continuity together, and symmetry perfected together with continuity is the first pairing that the theorem forbids. The Modern Engagement, Chapter 7, Section VII, applies the theorem to consciousness. In that section knowing is third-person and has the nature of symmetry, while understanding is first-person and has the nature of continuity. In The Modern Engagement, Chapter 7, Section VII, I conclude: "No amount of omniscient-modal description will ever produce immanent-modal understanding, for the same reason that no amount of symmetry will ever produce continuity". Integrated information can therefore describe, exactly and usefully, the structure within which a system's acts of comparison occur. Integrated information cannot be the act of comparison itself.

The collection already distinguishes, for one physical quantity, between the act and the physical circumstance under which the act occurs. The quantity is criticality. Integrated information falls on the same side of

the distinction as criticality. Causality Without Determinism, Chapter 5, Section IX, asks whether the brain's poise between order and disorder is consciousness, and answers: "The brain's poise between order and disorder, which physicists call criticality, is the physical circumstance under which the bound triple is expressed in us; it is not the bound triple itself". Integrated information stands where criticality stands. High integration of a system's causes and effects upon itself is a physical circumstance under which acts of comparison gather into one stance, and a system lacking it has no single place where its choices gather. When a system's parts act strongly and irreducibly on one another, the system's many acts of comparison can be made from one side, by one self. Integrated information is the measure of that circumstance, and not the inside that the circumstance supports.

A second point of parting follows from the first. Integrated information is computed from a system's transition probabilities, and the definition of integrated information allows every outcome to be fixed by the system's prior state. So a network of logic gates can have high integrated information even when every next state of the network follows from its present state by a rule, and the theory then assigns the network experience. A logic gate is a simple switching element of the kind that computers are built from. Each gate sets its output from its inputs by a fixed rule. The computer scientist Scott Aaronson pressed the point in 2014 with large networks of simple logic gates wired as expander graphs. An expander graph is a network in which every small group of elements is wired to many elements outside the group. On the theory the expander networks are conscious, although they do nothing that a person would call experiencing. In reply Tononi accepted the consequence, and he extended the consequence to a plain two-dimensional grid of logic gates. The collection rejects the consequence, because a system whose every step is fixed by a rule has no hard randomness of its own, and with no hard randomness the system's order of states is an indexing and not an arrow. With neither hard randomness nor an arrow, the system has no subjective. A physical grid of gates is a physical system that interacts with itself and

with its surroundings. On the collection's account the grid has whatever its interactions have: something real and simple, as a thermostat's interaction with temperature is real and simple. The integrated information of the grid is computed from the grid's rule, and the rule supplies none of what the grid's interactions have. On wholly determined systems, the collection is stricter than the theory. Where a rule has no hard randomness, integrated information computed from the rule is integration of a determinism, and a determinism, being a rule, has no inside.

## V. Grades of Experience and Choice in Every Degree

On Integrated Information Theory, consciousness is graded, and even very simple systems have some consciousness. A photodiode is a small electronic part that responds to light, and a one-bit memory holds a single yes or no. Tononi and Koch suggest that a single photodiode linked to a one-bit memory "can have a modicum of experience". Critics often count the photodiode's modicum of experience against the theory. The collection holds something close to the consequence that a photodiode can have a modicum of experience. Hard randomness and choice are one event described from two positions. The collection applies the two descriptions to the simplest physical system that the collection treats: a particle in the free will theorem, a theorem of quantum physics whose conclusion is that a particle's response to certain measurements is not fixed by the particle's past. The undetermined response of the particle is, "described from outside, hard randomness; described from the position of the process from which it came, the same event is choice" (Causality Without Determinism, Chapter 5, Section V). On the collection's account, choice is present in every degree: wherever an outcome is not fixed in advance, choice is present in some degree. The Modern Engagement, Chapter 7, Section V, draws the consequence for consciousness: "Wherever interaction occurs, some form of consciousness is present". Panpsychism is the view that matter itself, down to its smallest parts, has some form of mind. Chapter

7, Section V, of The Modern Engagement states that the view of consciousness as present wherever interaction occurs "is structurally different from panpsychism", because consciousness is a property of interaction and not of matter. So the collection's account "does not begin from micro-experiences that must somehow be combined". Integrated Information Theory also avoids the problem of combining small experiences into one experience. The theory avoids the problem by its exclusion postulate, which states that only the maximally irreducible whole is a subject.

The collection states what the degrees of consciousness correlate with. The Ground of Objection, entry T3.19, states: "consciousness is a property of interaction whose degree and kind correlate with the richness and structure of the interaction. A thermostat's interaction with temperature is real and simple. A brain's interaction with a world is real and enormously complex". The same entry states what the collection asserts and what the collection asks for: "The correlation between richness of interaction and degree of consciousness is asserted and is not derived, and the system does not supply a measure of richness or a function from one to the other". So the collection asks a question: what measure of the richness and structure of an interaction tracks the interaction's degree of consciousness? Integrated information is a measure of the richness and structure of interaction: a measure of how richly and irreducibly a system's parts act upon one another. In the collection's terms, integrated information is a candidate for the measure of the structure of a system's interactions. A measure of that structure would be the omniscient signature of the degree of consciousness, the mark that the degree of consciousness leaves in structure laid out from outside. The collection gives predictive utility the same standing in its treatment of Dennett: predictive utility, the usefulness of ascribing a belief to someone for predicting what the person will do, is "a real feature of belief, its omniscient-modal signature". The collection rejects the theory's further step, the step that says the measure is the experience. As a measure of the richness of interaction, integrated information would be computed over a system's physical interactions, hard ran-

domness included, and not over the rule that describes the interactions. For the grid of Section IV, integrated information computed from the grid's rule is high, while the grid's interactions are simple.

Integrated Information Theory and the collection differ in what the grades are grades of. For Tononi the grades are amounts of one quantity, integrated information, and the quantity is the experience. For the collection the grades are degrees of the interaction itself, and in the richest interactions the choices made are held together by one self that persists. Causality Without Determinism, Chapter 6, Section VI, defines the self: "The self, as An Immanent Metaphysics defines it, is the appearance of the aggregation of that aspect of interaction which is choice. Self is an intrinsic of choice". A photodiode's single undetermined click is choice at its least gathered, while a living person is choice gathered across every channel of perception into one persisting stance. Tononi's exclusion axiom, "Experience is definite: it is this whole", refers to the same gathering of choice into one stance: one stance, one whole, at a time. The collection adds what makes the gathering a self and not only a structure: the stance persists without a break, while what the stance meets changes. The persistence and the change are the first two of the four theorems of being, which the Immanent Metaphysics states: "Subjective context is continuous: the persistence of self-identity. Subjective content is discontinuous: the diversity of thoughts and perceptions" (Chapter 6, Section VII).

## VI. Distinctions, Relations and the Act of Comparing

Tononi's composition axiom says that experience is "composed of distinctions and the relations that bind them together". The composition axiom's description is close to the collection's own description of what any finding contains. A finding is an interaction that registers which of several alternatives is the case. A comparison returns a verdict of same or different, in some respect, and every finding is built from verdicts of that kind and from the relations among the verdicts. On the collection's account, percep-

tion is a comparison considered from the side of the self (Causality Without Determinism, Chapter 4, Section IX). So the theory's structure of distinctions and relations is the structure of the verdicts that a system's comparisons return.

The collection keeps the verdicts apart from the act that returns them, because the act is held in the first person, while the verdicts, once returned, can be laid out and surveyed. When a structure of distinctions and relations is held in view as a whole, the structure is a record: the laid-out side of the act. Tononi identifies experience with the structure of distinctions and relations, and so he takes the record of experiencing for the experiencing. The qualities of experience are what philosophers call qualia. The collection's treatment of Dennett makes a parallel claim about qualia: qualia "have the nature of non-local context and are characterized by continuity. They cannot be picked out by any procedure that works by distinguishing content, because they are not content" (The Modern Engagement, Chapter 8, Section IX). Computing a structure of distinctions is a procedure that works by distinguishing content. Tononi holds that the structure fully specifies the quality of an experience. The collection holds that the axioms of the Immanent Metaphysics "predict the structure of consciousness, not the content of any particular experience, so that qualia are not derived from them" (The Modern Engagement, Chapter 7, Section XV). The structure is real, and a person who computes the structure gains real knowledge about a system. But the structure is the omniscient side, the side laid out, of something whose own character is immanent: held in the act, as the act happens.

## VII. The Charge of Pseudoscience, and What a Measurement Can Reach

In 2023 more than a hundred researchers signed an open letter calling Integrated Information Theory pseudoscience, and the letter was posted on PsyArXiv, a public site for papers in psychology. The central complaint of

the letter was that some aspects of the theory had been tested, but "the theory as a whole has not". So, the letter said, there was "little experimental support" for the theory's "bold and counter-intuitive implications". Other researchers called the letter "poorly reasoned and disproportionate". The letter's authors later published a commentary, and in 2025 Tononi and colleagues answered the commentary in *Nature Neuroscience*, writing that the commentary had "much fervor and little fact". An adversarial collaboration is a study designed jointly by the proponents of rival theories, who agree in advance on which results would count against each theory. Global neuronal workspace theory is a rival theory of consciousness, on which a content becomes conscious when the brain broadcasts the content widely across its regions. In April 2025 *Nature* published the results of the adversarial collaboration between proponents of Integrated Information Theory and proponents of global neuronal workspace theory. Each theory's predictions about where and when the brain's activity tracks conscious perception came out partly right and partly wrong. Oscar Ferrante was one of the leading authors of the study, and he summarized the results: "Both theories are incomplete".

The dispute over the letter mixes two kinds of claim, and the collection's distinction between the two kinds settles what each side can ask. Physics Is Not Math, Chapter 19, Summary, states where a test applies: "A test applies where the outcome of a comparison can be objective: comparable by many, consistent across them, and able to surprise". Integrated Information Theory makes claims about which regions of the brain carry the activity that goes with reported perception, and the outcomes of those claims can be objective in that sense. The adversarial collaboration tested those claims properly. The central claim of the theory is of another kind: the claim that an experience is the cause-effect structure of the system that has the experience. Experience is held in the act of experiencing, in the way that a performed claim is held. No third-person measurement takes another's first-person act as its content, so the central identity of the theory is a metaphysical claim, and no experiment can confirm or refute the identity.

The Ground of Objection, entry T1.10, sets out what follows when the philosopher Karl Popper's own criterion is applied to a metaphysical claim. Popper's criterion "is a criterion of demarcation and expressly not of meaning": the criterion marks the boundary between empirical science and other claims, and it does not judge whether a claim has meaning. On Popper's account metaphysical statements "are not nonsense ... may be fruitful, and are simply not scientific". So "a system placed outside empirical science by his criterion has not been convicted of anything by him". The collection accepts Popper's demarcation for itself. The collection places its own foundational claims outside empirical science "without embarrassment". The physical predictions of the collection, by contrast, are offered to measurement. The collection's foundational claims include the claim that a computation cannot be what consciousness is. The claim concerns what a computation is, and the claim is checked by the structure of its argument, step by step, as a logical claim is checked. The open letter was right that the theory's central identity has not been tested by experiment, but the letter was wrong to treat the absence of a test as a conviction, because Popper's criterion places the identity outside empirical science and convicts the identity of nothing. Tononi and his colleagues made the charge possible, because they presented the central identity inside a scientific theory and did not mark where the empirical claims end and the metaphysical claim begins. The collection draws that line for itself. A metaphysical claim is judged by its argument, and the argument for the identity fails at one step: the step that sets a surveyed quantity equal to a performed act.

The sealed record is the register of the predictions of physics from comparison that I sealed, fixing its wording, and that I do not revise. Appendix F is the register that sets Tononi's model beside the sealed record, and Appendix F finds that "no measurement made or proposed separates the two accounts". The collection makes no statement about which regions of the brain, or which patterns of their activity, go with conscious perception. Integrated Information Theory makes no prediction about gravitation, cosmology or the kinds of particle, and the predictions that

the sealed record holds are about gravitation, cosmology and the kinds of particle. The collection's books make one statement that bears on the brain and can be measured: the brain operates near criticality. The sealed record does not carry the statement about criticality, and the measurements so far agree with the statement. Integrated Information Theory and the collection have true differences, and the true differences are of a kind that no experiment can decide. The differences concern what experience is, whether a wholly determined system can have experience, what fixes the quality of an experience, and what the grades of experience are grades of.

## VIII. Summary

Integrated Information Theory is the scientific theory of consciousness nearest to the collection's account. Tononi begins the theory from experience itself, with a first axiom that is a performed claim, and he names the subjective in his axiom of intrinsicality. Tononi places consciousness in a physical system's causal power upon itself, and by the collection's Root Tautology a system's causal power upon itself is the comparisons that the system makes within itself. The theory denies consciousness to feedforward networks and to simulations on digital computers, for the reason that the collection gives: what counts is the physical process, never the program it runs.

Integrated Information Theory and the collection part where Tononi passes from his axioms to his measure. Integrated information is a surveyed quantity, computed from a system's structure as laid out from outside. On the collection's account, consciousness is the bound triple of the arrow of time, hard randomness and the subjective, taken as one act, and consciousness is held in the act. The Incommensuration Theorem keeps the objective and subjective characters apart, so no objective quantity can be the subjective act. Integrated information measures the circumstance under which acts of comparison gather into one stance, as criticality does. The theory computes a structure of distinctions and relations, and the

structure is the laid-out record of the verdicts that the acts of comparison return. The measure allows every outcome to be fixed, so the theory grants experience to wholly determined systems, which the collection holds have no inside. The theory begins with Chalmers' datum and ends with a third-person description of the kind that Dennett offered. On both accounts, something of mind is present at every scale. For the theory, what is found at every scale is an amount of integration. For the collection, what is found is interaction, whose degree of consciousness correlates with the interaction's richness and structure, together with choice, which is gathered into a self where interaction is richest. The collection asks what measure of the richness and structure of interaction tracks the degree of consciousness. Integrated information is a candidate for that measure, but integrated information is not the experience that it measures. The charge of pseudoscience fails on Popper's own criterion: the theory's central identity is a metaphysical claim, to be judged by its argument. Tononi measures the structure of a system's causes upon itself. In the next chapter the neuroscientist Karl Friston describes every thing that persists by the boundary across which the thing meets its world, and Friston reads perception and action as inference, the drawing of conclusions from evidence.

**Key Concepts**

- Integrated Information Theory starts from axioms of experience, and its first axiom, "Experience exists", is a performed claim, held in the act.
- Both accounts deny consciousness to feedforward networks and to programs as such, because what counts is the physical process, never the program.
- The theory's causal power of a system upon itself is, in the collection's terms, the comparisons that the system makes within itself.
- Integrated information is a surveyed quantity, while consciousness is the bound triple taken as one act, and the Incommensuration Theorem keeps the objective and subjective characters apart.
- Integrated information measures a circumstance, as criticality does, and is not the inside that the circumstance supports.
- A wholly determined system has no hard randomness, so the system has no arrow and no subjective, whatever its integrated information.
- The theory begins with Chalmers' datum (experience is real and not captured by function) and ends with a third-person description of the kind Dennett offered.
- Both accounts deny that a physical duplicate of a person could lack experience, and both allow a behavioral duplicate with no inside.
- In the theory, grades of experience are amounts of integration; in the collection, the grades are degrees of interaction, correlated with the interaction's richness and structure; integrated information is a candidate measure of that structure, and not the experience.
- The theory's identity of experience with structure is judged by its argument, not by experiment, and the argument fails where it sets a surveyed quantity equal to a performed act.

## Terms

**Bound triple.** The arrow of time, hard randomness and the subjective: distinct, inseparable and not interchangeable; taken as one act, consciousness.

**Cause-effect power.** In Integrated Information Theory, what a system's parts in their present state specify about the system's past and future states.

**Feedforward network.** A network whose signals pass only from input toward output, with no part acting back on another.

**Hard randomness.** An outcome that no prior specification fixes, however complete; described from inside, choice.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Integrated information.** In Integrated Information Theory, the measure of how far a system's cause-effect power upon itself cannot be reduced to that of its parts.

**Performed, surveyed, implied.** The three ways a claim can be held: by what happens in the act of engaging it; from a vantage with many cases in view; in the stance a practice proceeds from.

**Root Tautology.** Comparison, interaction and relation are one act under three names.

**Self.** In the collection, the appearance of the aggregation of choice.

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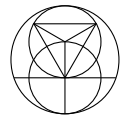

Karl Friston

# The Boundary and the Act

*Karl Friston's Free Energy Principle and Physics from Comparison*

## Abstract

Karl Friston, a neuroscientist, states his free energy principle about anything that persists as a thing, set apart from its surroundings by a boundary of sensory and active states. Friston holds that such a thing behaves as if it were inferring the causes of its sensations, and as if it were acting to keep those sensations within the range its own existence requires. So, on Friston's account, perception is inference, action is inference carried into the world, and a living system is a system that gathers evidence for its own continued existence. The physics collection of the Immanent Metaphysics is the set of books that set out physics from comparison. The collection shares more of Friston's picture than the words of Friston and of the collection suggest. In the collection, as in Friston's account, a thing is set apart from its world by a boundary across which it interacts. The thing is never wholly cut off from its world and never wholly merged with it. In the collection, perception is comparison. And the question Friston asks, "if things exist, what must they do?", has the same form as the collection's own question, which asks what an act of comparison cannot fail to contain. Friston also says plainly that his principle is a mathematical statement and not a falsifiable theory (a theory that some observation could show to be false). The collection agrees with him on exactly where a test applies and where it does not. Friston's account and the collection

part on what comes first. Friston begins from probability densities over the states of a system and from a statistical partition of those states, and he reads a self, a perception and a choice off that mathematics. The collection begins from the act of comparison and derives probability from that act. The collection also holds that a description laid out from outside, however exact, leaves out the stance (the side from which a comparison is made) from which a self perceives and chooses. In this chapter I set out the free energy principle at full strength and credit what Friston establishes with it. Then I show where and why the collection parts from Friston. The collection parts from him on the boundary of a self, on the difference between a model of inference and the act of comparing, on choice, and on the order of mathematics and physics.

## I. The Principle

Karl Friston, a neuroscientist at University College London, set out the free energy principle in 2006, with James Kilner and Lee Harrison, as an account of the brain. In 2010 Friston offered the principle as a candidate for a unified theory of brain function. His later statements of the principle extend it from brains to every system that persists, and in a monograph of 2019 he extends it to physics itself. The monograph of 2019 describes its own aim in these words: it "attempts a theory of every 'thing' that can be distinguished from other things in a statistical sense".

The free energy principle has three parts, and the first part is the boundary of a thing. Friston picks out a thing by a *Markov blanket*: a set of states, the sensory states and the active states, that separates the thing's internal states from the external states of its world. The blanket separates the internal states from the external states in such a way that the internal states depend on the external states only through the blanket. The world influences the sensory states, and the sensory states influence the inside of the thing. The inside influences the active states, and the active states influence the world.

The second part of the principle is a quantity. Where a thing has a Markov blanket, Friston reads its internal states as encoding a probabilistic model of the external causes of its sensations. The *surprise* of a sensation is how improbable the sensation is under the thing's model. The system can compute a quantity called *variational free energy*, which is never less than surprise, while the system cannot compute surprise itself directly. Friston argues that a thing that persists is a thing whose internal and active states change so as to keep its free energy low. The thing keeps its free energy low, and so it keeps its sensations within the range of states compatible with its continued existence.

The third part of the principle is the reading Friston gives of the two kinds of change, change in the internal states and change in the active states. When the internal states change so as to lower free energy, Friston reads the change as perception, and he reads perception as inference. In perception the internal states come to encode the most probable causes of what the thing senses. When the active states change so as to lower free energy, the change is action, which Friston calls *active inference*: the thing changes the world so that what it senses fits what it expects. The system selects among courses of action by expected free energy, a quantity that weighs both the value of reaching preferred states and the value of the information an action would gather. Friston calls a system that persists by perceiving and acting in these ways *self-evidencing*: by acting, the system gathers evidence for the model that its own existence embodies.

Friston and his colleagues are exact about what kind of claim the free energy principle is. They compare the free energy principle to Hamilton's principle of least action in a paper of 2023 in the journal Physics Reports, "The free energy principle made simpler but not too simple". Hamilton's principle is the principle that a system moves along the path for which a quantity called the action is stationary (unchanged, to first order, by any small change of the path). The equations of motion of classical mechanics follow from Hamilton's principle. Of their own principle, Friston and his colleagues write that "it is not a falsifiable theory about the way 'things' behave". They also write that "the FEP [the free energy principle] is not

falsifiable as a mathematical statement, but it may as well be falsifiable to the extent that its postulates refer to a specific class of empirical phenomena that the principle aims to describe". They put the central question of the principle in a turned form, "if things exist, what must they do?", and do not ask simply what things do.

Jelle Bruineberg, Krzysztof Dołęga, Joe Dewhurst and Manuel Baltieri raised a serious objection to the central term of the free energy principle, the Markov blanket, in their paper "The Emperor's New Markov Blankets" (2022). They traced the Markov blanket to its origin in the work of Judea Pearl on Bayesian networks (diagrams of the probabilistic dependence among variables), where the blanket is a tool of inference within a model. From that origin they followed the blanket to Friston's use of it, which is to mark the real boundary between an agent and its world. They proposed "to distinguish between 'Pearl blankets' to refer to the original epistemic use of Markov blankets and 'Friston blankets' to refer to the new metaphysical construct". They argued that inference with a model must be told apart from inference within a model. On their argument, only inference within a model can do metaphysical work (saying what the boundary of a real thing is), and even then only with further premises.

## II. What the Principle Establishes

Friston derives four results from the mathematics of probability. The collection derives the same four results from the structure of comparison, that is, from the parts that every act of comparison must contain.

The first result is that a thing is a thing by a boundary across which the thing interacts with its world. Friston's Markov blanket makes the inside of a thing depend on the outside only through the boundary, and the blanket also keeps the inside and the outside coupled through the boundary. So the thing is never sealed off from its surroundings and never dissolved into its surroundings. The collection says the same of the self, in its book Causality Without Determinism, Chapter 6, Section VI: the self "par-

ticipates in interaction: it perceives, it chooses, it is embedded in a domain. The degree of its interaction is never zero (it is always engaged with something) and never infinite (it is never identical with the totality of what it interacts with)". The collection's principle of non-polarization requires an interaction that is never zero and never infinite, and the passage just quoted applies that principle to the subject, the self. The Markov blanket is a mathematical form of the principle of non-polarization.

The collection has already set out its relation to two traditions that bear on active inference, and each of the two traditions places mind at the boundary where Friston places his blanket. The first tradition is the cybernetics of Gregory Bateson, the study of control and communication, which Bateson carried into an account of mind. The collection holds that "mind is the immanent aspect of self, the boundary and the dynamics between internal subjective quality and external objective form". In the collection, the immanent is what is held in the act of comparison itself. The collection also holds that its account and Bateson's both "deny that mind is a substance and affirm that mind is a process" (The Immanent Metaphysics and the Modern Engagement, Chapter 12, Section V). The second tradition is the enactivism of Francisco Varela and Evan Thompson, the account of cognition as something a living thing enacts in its coupling with its world. The collection takes from enactivism its unit of comparison, "the living organism in its environment, taken as a single relational whole". On the enactive account, cognition "happens at the boundary, in the interaction, in the structural coupling of organism and world". In the chapter on enactivism, I call enactivism "the closest contemporary scientific parallel" to the collection's account of perception (The Immanent Metaphysics and the Modern Engagement, Chapter 9). Friston places the inside, the outside and the coupling between them in one formal object, the Markov blanket. The collection places mind at that same boundary, as the dynamics across the boundary.

The second result is that perception is what a living system does with what arrives at its boundary, and that perception is the same act as the measurement an instrument makes. Causality Without Determinism,

Chapter 4, Section II, states the result this way: "Measurement is a comparison; so is perception, and so is every interaction". The same section adds: "The comparer is a structural role, the role of relating, and a mind, an instrument or a thermostat can fill it". Friston's principle applies alike to a cell, a brain and a controller like a thermostat, and it applies to all three for the same reason as the collection's account does. The principle concerns what anything bounded does at its boundary, and not what material the thing is made of.

The third result is that the central operation of Friston's account is a comparison. In Friston's account, a prediction error is the verdict on what the system senses set beside what the system expects. The verdict says whether what is sensed and what is expected are the same or different, and by how much. In the collection's terms, the content of a prediction error is what is sensed (a brightness, a pressure, a sound), and the context is the expectation against which the system judges what it senses. Every comparison has both a content and a context, and "the content and the context cannot be one respect" (Comparison; The Necessary Basis, Chapter 4, Section I). The collection describes the recognition of a face as three comparisons made in order: the face is found near enough to register, then found like something held in memory, then taken in as one's own (Comparison, Chapter 8, Section VI). Friston's account has a hierarchy of predictions, in which each level compares what arrives from the level below with what that level expects. That hierarchy is the collection's sequence of three comparisons, written as mathematics. A prediction error is also what Bateson called a difference which makes a difference. The collection says exactly what that difference is: it is "the epistemic face of difference", "the difference of content in a sameness of context". Every comparison contains six parts, and difference is one of them. The difference Bateson named is one face of that part, the face that bears on knowing (The Immanent Metaphysics and the Modern Engagement, Chapter 12, Section VI).

On the scope of the principle, Friston agrees with the collection. Friston's principle applies to every thing that can be set apart from its surroundings, whether the thing is living or not. Thompson holds that life and mind are continuous, and his continuity has a lower bound at life: below life, Thompson does not commit to anything that could be called sense-making. The collection's three modalities are the three roles in every comparison: the immanent (held in the act), the omniscient (held as structure laid out) and the transcendent (implicit, held in the stance). The collection holds that the three modalities "are not features of living systems alone. They are features of reality as such", and that they "do not emerge at some threshold of biological complexity" (The Immanent Metaphysics and the Modern Engagement, Chapter 9, Section VII). Friston extends the principle from brains to every particle-like thing, and so he too refuses to draw a line where the structure of things draws none.

The fourth result is that Friston and the collection ask the same form of question. Friston's question is "If things exist, what must they do?", and it asks what must hold of anything at all, given only that it is a thing. The collection asks what an act of comparison cannot fail to contain, given only that it is an act of comparison. The answer is six parts in three pairs: same and different, content and context, and the subjective and the objective. The collection proves the Incommensuration Theorem from that answer. So both accounts reason from what anything of a kind must be, and not from a survey of cases. The right question for a foundation has the form 'what must anything of this kind be?', and Friston asks a question of that form of living things and of every other thing that persists.

Friston also gives novelty its weight in his principle. Expected free energy weighs the information an action would gather. So a system governed by expected free energy seeks out what it prefers and also what it does not yet know. The collection makes novelty one of the three conditions of objectivity, beside comparability by many comparers and consistency across them. On the collection's account a thing is known as separate from oneself only if it can surprise. To surprise is "to show what no one expected or could have fixed in advance; what does only what one expects

is not known as separate from oneself" (Physics Is Not Math, Chapter 19, Section III). In the quoted passage, 'surprise' has its everyday sense, to show the unexpected, and not the technical sense that Friston gives the word. A self that took in only what it expected would lose its world as a world, that is, as something separate from the self. Friston's epistemic term is the part of expected free energy that weighs the information an action would gather. That term keeps the world in view, and on this point Friston and the collection agree.

## III. Where a Test Applies

The collection reads Friston's statement that his principle is not falsifiable as a correct account of what kind of claim the principle is. Some readers expect every claim to be tested, and they may see a weakness in Friston's statement. The collection's account of where a test applies shows why the statement is no weakness. The collection's book Physics Is Not Math, Chapter 19, Section III, gives that account. A test "is a comparison of outcomes, and it can settle something only when its outcome can be compared: by another person, at another time, along another route". In Physics Is Not Math I conclude that "a test applies exactly where the outcome of a comparison can be objective, and nowhere else". A mathematical statement is not the outcome of a comparison in this sense. In the collection's terms a mathematical statement is a surveyed claim. A surveyed claim is established "from a vantage that holds many cases in view at once, by counting the cases or by proving, from fixed premises, what holds in every case they cover" (Physics Is Not Math, Chapter 9, Section III). So a mathematical statement is checked by proof.

When the free energy principle is stated as mathematics, it is checked the way Hamilton's principle is checked: by whether its conclusions follow from its premises. Measurement can test every claim that applies the principle to a particular system. One claim of that kind is that a given population of neurons encodes a given prediction. Another is that a given

cell's membrane is the boundary across which the cell's states are coupled in the way the principle requires, and another still is that a given behavior lowers a given quantity. Each of these claims is a claim about the world whose outcome many people can compare, and so a test can settle it. In his own program Friston draws the same line, between the principle and the process theories that realize the principle in particular systems. Predictive coding is one of those process theories: it is the theory that the brain predicts its own input and passes on mainly the errors of its predictions. The paper of 2023 says that the principle "may as well be falsifiable to the extent that its postulates refer to a specific class of empirical phenomena that the principle aims to describe". So the collection and Friston divide the principle from its applications at the same place. The collection also leaves to the sciences, each in its own domain, the question of which mechanisms there are. The Ground of Objection, entry T2.24, holds that "the system entails that comparison has implementations": neurons firing and signals crossing are interactions, and so they are comparisons. A description of the mechanisms that implement comparing "is a description within a domain". Such a description does not displace the collection's account, and the collection's account does not displace the description. Predictive coding describes how a brain implements its comparisons, and so predictive coding is a description within a domain in this sense.

Friston and the collection also both place their foundations outside empirical science, and both do so openly. The Ground of Objection, entry T1.10, accepts the criterion of the philosopher Karl Popper as the line that marks off empirical science. Popper's criterion is that a claim belongs to empirical science only if some observation could show the claim to be false. The entry places the collection's foundation outside empirical science "without embarrassment": "a system placed outside empirical science by his criterion has not been convicted of anything by him". So Friston and the collection make statements of the same kind, Friston about his principle and the collection about its own ground: each statement openly places a foundation outside empirical science.

The collection adds one distinction that Friston does not draw. The free energy principle is a surveyed claim: it holds of every model that satisfies the principle's conditions. The Incommensuration Theorem is a performed claim: it is "established by what happens in the act of engaging it, including the act of trying to deny it" (Physics Is Not Math, Chapter 9, Section III). The Incommensuration Theorem is a structural fact about the nature of knowing: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The collection proves the theorem from the meanings of the parts of comparison, as I say in Section II of this chapter. The theorem is also performed, because any attempt to deny the theorem is itself a comparison. So proved and performed are two ways in which the one theorem is held. Every inference that the free energy principle describes is an act of comparison, and so is every check of the principle itself. So the theorem holds in each of those acts before the principle is applied. The free energy principle lies outside what a test can settle because the principle is mathematics. The Incommensuration Theorem lies outside what a test can settle because every test is an instance of the theorem. I formulated the first axiom of the Immanent Metaphysics in or before 1991, and the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996. I did most of my physics work in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1.

## IV. The Boundary of a Self

Friston's account and the collection part at the point where Bruineberg and his colleagues raised their objection. A Markov blanket in a model is a fact about a probability distribution: once the blanket states are given, the internal and the external variables are independent of each other. When a Markov blanket is read as a Pearl blanket, the blanket says something about the model. When the same Markov blanket is read as a Friston

blanket, Friston means the Markov blanket to say what the boundary of a living thing is. Bruineberg and his colleagues object that the step from the Pearl blanket to the Friston blanket needs further premises.

The collection names the step from a Pearl blanket to a Friston blanket. Causality Without Determinism, Chapter 4, Section I, states the point this way: "Compatibility between a model and a body of measurements is not equivalence: many models may be compatible with the same data, and no amount of compatibility can establish that the model is the reality it describes". The same section states it again in one sentence drawn from the Incommensuration Theorem: "A law exists; a measurement is real". In the collection's sense, a statistical partition of a model exists: the partition is structure laid out, the same for every reader. The boundary of a cell or a self is real: the boundary is the place where interactions happen, one at a time, each from a side. So the gap between Pearl blankets and Friston blankets is the gap between what exists and what is real. No further premise of statistics can close that gap, because the premise needed is not a statistical premise. The premise needed is that the partition of the model marks a place where comparisons are made. That premise is true of living things, and it is also true of every bounded thing, since every interaction is a comparison. The boundary of a self differs from other boundaries in one way. Across the boundary of a self, the comparisons are made from one side, by one self that carries those comparisons forward as its own. The collection supplies the ground of the premise: the boundary of a self is where the self compares, perceives and chooses. A Markov blanket can describe the boundary of a self exactly. But the Markov blanket cannot be what makes that boundary, because a partition laid out in a model is held from outside, while the boundary of a self is held from the side of the self.

A family of theories of perception has the same structure as Friston's account: a hidden world known only through a boundary. The collection answers that family of theories in The Basis of Physics, Essay 4, Section VI. In those theories "everything we perceive comes to us through an interface", while a hidden reality lies behind the interface. Essay 4 asks whether the translation from the hidden level to the interface is real. In Essay 4

of The Basis of Physics I find that if the translation is real, the translation is an interaction, and so the translation is privileged in exactly the sense that the interface theories denied. In Friston's account the external states are hidden behind the blanket and known only by inference. The collection holds that the blanket itself is the place where the world is met. The sensory states are the comparisons in which the self finds the world, and they are not a veil between the self and its world.

Friston's generative model is the probabilistic model of the external causes of sensations that, in Section I, the internal states encode. The collection's account of representation says where Friston's generative model belongs. In its chapter on enactivism, the collection holds, with the enactive tradition, that "all of one's experiences are direct experiences" and that "there is no such process as direct perception; there is only direct experience". That chapter also holds that representation "is a legitimate tool within the omniscient modality. But it is not the ground of knowing" (The Immanent Metaphysics and the Modern Engagement, Chapter 9). Friston's generative model is that legitimate tool, representation, held exactly. The generative model seems to reopen an old question: does a self have its world, or only a model of its world? The Ground of Objection, entry T2.12, answers the old question by changing the kind of answer. On that answer, objectivity "is not an attribute of any single perception", but a measure computed over many acts, by the three rings of verification (intensity, consistency and novelty). The entry adds that "a single perception is simply real and has no degree of objectivity, any more than a single measurement has a variance". A variance is the spread of many measurements about their mean. So each perception is an act in the world, and no perception is a proxy for the world. The world becomes known as objective across many acts of perception.

## V. Inference and the Act

The free energy principle describes a self from outside, as a dynamical system whose internal and active states flow down a gradient of free energy, with random fluctuations added. To flow down the gradient is to change in the direction in which free energy falls. Friston's description can be exact, and still the collection holds that the description leaves something out, for a reason the collection states precisely.

A computer can run Friston's description of a self as a program. A simulated agent governed by active inference is a program. Causality Without Determinism, Chapter 5, Section II, defines a program as "a step-by-step procedure whose next state follows necessarily from its current state by a fixed rule". So the argument of that chapter applies directly to a simulated agent governed by active inference. The argument starts from what consciousness is. Consciousness is the bound triple taken as one act: the arrow of time, hard randomness and the subjective, distinct, inseparable and not interchangeable (the same chapter, Section III). Hard randomness is an outcome that no prior specification fixes, however complete. A classical computation is symmetry perfected, one rule applied the same way at every step. A classical computation lacks the arrow and lacks hard randomness of its own, and, since the three parts of the triple are bound together, it also lacks the subjective (Section VI). So "classical computation, however intricately organized, cannot be what consciousness is", and an artificial agent that minimizes free energy, however faithfully, is a classical computation and no exception. The same chapter allows that such an agent may behave, as seen from a third-person vantage, in a way that no one can tell apart from conscious behavior. The argument concerns what the act of the agent is, and not which outputs of the agent can be matched. Thinkers of the enactive tradition reach the same conclusion on their own ground: a computational system "does not enact a world; it manipulates symbols" (The Immanent Metaphysics and the Modern Engagement, Chapter 9).

The collection's account of the act also has a place for the random fluctuations in the equations of the free energy principle. In Friston's model the fluctuations are a term with a fixed distribution, set beside the deterministic flow down the gradient of free energy. Causality Without Determinism, Chapter 5, Section V, distinguishes two things called random. The first of the two things called random is pure randomness, an outcome with no relation to anything. Pure randomness is an idealization: the Incommensuration Theorem forbids it as an absolute, as the theorem forbids determinism. The second of the two things called random is hard randomness, and hard randomness is real: "the remainder that no completeness of prior specification closes off". Hard randomness and choice "are one event described from two positions". From the position of law the event is a gap in the specification, and from the position of the one engaged the event is a choice. The fluctuation term of the free energy principle is the description from the position of law. The description from the position of law is correct, and it describes from outside what is, from inside, the agent choosing.

## VI. Decision and Choice

An agent governed by active inference selects a course of action by comparing the expected free energy of each course in a set of courses. The agent favors the course with the lowest expected free energy. The collection has an exact name for that operation of selection: decision, as distinct from choice. Causality Without Determinism, Chapter 6, Section III, draws the distinction: "A decision is a selection from a set of possibilities already defined, made by cutting away the others; if it involves trade-offs, it is a decision. A choice may realize a possibility that was open but not in the set. Decision engages causality: it weighs what is known to follow from what. Choice engages creation".

Friston calls a course of action a policy. Policy selection by expected free energy is decision in this sense. Decision in this sense covers a great part of what living things do: a habit, a reflex, a weighing of known outcomes. The collection's account of the real places decision and choice in one structure. The collection's triple of the real has three parts, one in each modality: change is immanent, causality is omniscient and choice is transcendent. Change, causality and choice run in one order, from choice to change to causality and back to choice (Causality Without Determinism, Chapter 6, Section II). Where every action in a model is the outcome of minimizing a quantity over a set, the model reads that cycle from causality first. Chapter 6 of Causality Without Determinism warns that reading the cycle that way "leaves choice out of the cycle and reduces it to an effect of what came before". The free energy principle describes the causal side of a living thing completely enough to be useful in every laboratory that uses the principle. The collection finds choice in what the principle describes as fluctuation, and in any course of action that falls outside the set of courses the principle ranks.

## VII. Probability and the Order of Depth

The deepest parting between Friston and the collection is in the order of their accounts, that is, in what each account puts first. Friston's monograph of 2019 begins from probability densities over states and from the conditional independences among those states. A conditional independence is a way in which some states are independent of others once a third set of states is given. The monograph reads off things, their boundaries and their beliefs from that statistical structure. It also proposes to read off the forms of quantum, statistical and classical mechanics from the same structure. So in Friston's account mathematics comes first, and physics and mind are read from mathematics.

The collection orders the four domains the other way, with mathematics last: metaphysics, then physics, then computation, then mathematics, each presupposing the one before. Physics Is Not Math, Chapter 3, Section VII, says that mathematics "works as if only the objective existed, and as if there were no subjective side at all". The same section says: "What mathematics states leaves the stance out; how mathematics is done keeps the stance in". The collection derives probability itself, and does not assume probability. The collection's book The Quantum Passage, Chapter 7, derives the Born rule (the rule that gives the probability of each outcome of a quantum measurement) from the structure of comparison. Chapter 11, Section V of the same book sets out where the collection differs from the reading of quantum probabilities as an agent's degrees of belief, the reading called QBism. On the collection's account, what a measurement changes is the laid-out record, which is "shared and the same for everyone who has the outcome", and not a personal degree of belief (Chapter 9, Section IV). Friston's internal states encode beliefs in a model, while the collection's record of a comparison is a fact shared by every comparer who has the record.

Each parting found in the earlier sections of this chapter has one form, and the order of depth sets that form. The boundary of a thing is real before anyone writes a probability distribution over it. The comparison is made before any probability is assigned to its outcome. The choice is made before any fluctuation term describes it. In each case Friston writes, from outside and exactly, the structure that an act of comparison lays out, and in each case the act comes first.

Appendix G is the register that sets Friston's account beside the sealed record, and it records one agreement. The sealed record is the register of the predictions of physics from comparison, fixed at its date and not revised. The agreement is Prediction 25 of the sealed record, that the statistics of quantum theory hold. Friston's account shares Prediction 25, since his monograph of 2019 presents its Bayesian mechanics as compatible with quantum mechanics and names no departure from quantum mechanics. The measurements so far agree with both accounts. The register

states: “No measurement named in the relation essay or in the books separates the two accounts”. The relation essay named in the register is this chapter. The collection makes no claim about which mechanisms carry out comparing, and so the tests of predictive coding and of the other process theories bear on those theories and do not separate the two accounts.

## VIII. Summary

Friston and the physics collection describe the same living thing, and they start from opposite ends of the order of depth. Both accounts hold that a thing is set apart by a boundary across which it interacts, never sealed off and never dissolved. Both hold that perception is the comparison of what arrives at the boundary with what is held inside the boundary. Both hold that a living system must seek what it does not yet know. Both also hold that the right question for a foundation is a question about what anything of a kind must do or contain. Both agree on where a test applies: the principle, as mathematics, is checked by proof, and its applications to particular systems are claims about the world that tests can settle. Two traditions bear on active inference: Bateson’s cybernetics and the enactivism of Varela and Thompson. The collection’s accounts of both traditions place mind at the same boundary that Friston formalizes, as the dynamics across that boundary.

Friston and the collection part on what comes first. Friston begins from probability densities and a statistical boundary, and he reads perception, action and the self from that mathematics. The collection begins from the act of comparison and derives probability from that act. The collection holds that the boundary of a self is the place where comparisons are made, and that a Markov blanket can describe that boundary and cannot constitute it. Where a system governed by the principle is run as a computation, the system lacks the bound triple of arrow, hard randomness and the subjective. So the system is not what consciousness is, however exactly it behaves. The selection of actions by expected free energy is decision, the

weighing of what is known to follow from what. Choice may realize a possibility outside the set, and choice is what the principle describes from outside as fluctuation. The free energy principle is an exact third-person description of the causal side of living things, and the collection supplies the act that the principle describes. Friston's account is the last account of this volume. The appendices that follow give the Prediction Matrix of this volume and the dated registers that set each account beside the sealed record. The essay *Why the New Epoch Is Flat*, which gives the argument behind Prediction 9, is an appendix of Volume Five. The Prediction Matrix is the table that lists, for each sealed prediction, the models of this volume that agree and the models that differ.

**Key Concepts**

- The Markov blanket is a mathematical form of the collection's principle that a self's interaction with its world is never zero and never infinite. The collection places mind at the boundary the blanket describes, as the dynamics across that boundary.
- Friston's generative model is representation, which is a legitimate tool and not the ground of knowing. A single perception is simply real, and objectivity is a measure over many acts of perception.
- A prediction error is a comparison: a verdict on what is sensed (content) set against what is expected (context). A prediction error is also Bateson's difference which makes a difference, which the collection identifies as the difference of content in a sameness of context.
- The free energy principle is a surveyed claim, checked by proof. The Incommensuration Theorem is a performed claim, held in every act of comparison, including every check of the principle.
- The gap between Pearl blankets and Friston blankets is the gap between what exists (a partition laid out in a model) and what is real (a boundary where comparisons are made).
- A simulated active-inference agent is a computation, and it lacks the bound triple of the arrow of time, hard randomness and the subjective.
- The fluctuation term of the free energy principle describes from outside what is, from inside, choice. Active inference selects a course of action by expected free energy, and that selection is decision.
- Friston reads physics and mind from probability, while the collection derives probability from comparison.

## Terms

**Active inference.** In Friston's account, action that changes the world so that what is sensed fits what is expected.

**Bound triple.** The arrow of time, hard randomness and the subjective, distinct, inseparable and not interchangeable; taken as one act, they are consciousness.

**Content and context.** In every comparison, what the verdict is on, and the respect in which the two things compared are two.

**Decision and choice.** A decision selects from a set of possibilities already defined; a choice may realize a possibility open but not in the set.

**Expected free energy.** The quantity by which active inference ranks courses of action, weighing preferred outcomes and the information an action would gather.

**Hard randomness.** An outcome that no prior specification fixes, however complete; from the position of the one engaged, the same event is choice.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Markov blanket.** A set of states that separates internal from external states, so that each depends on the other only through it; Bruineberg and colleagues distinguish its use within a model (Pearl blanket) from its use as the boundary of a thing (Friston blanket).

**Performed and surveyed claims.** A performed claim is established by what happens in the act of engaging it; a surveyed claim from a vantage that holds many cases in view at once.

**Self-evidencing.** In Friston's account, acting so as to gather evidence for the model that one's own existence embodies.

**Surprise and variational free energy.** Surprise is how improbable a sensation is under a system's model; variational free energy is a quantity the system can compute that is never less than surprise.

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Pearl, J. (1988). *Probabilistic Reasoning in Intelligent Systems*. San Mateo, California: Morgan Kaufmann.

Thompson, E. (2007). *Mind in Life: Biology, Phenomenology, and the Sciences of Mind*. Cambridge, Massachusetts: Harvard University Press.

The books of the physics collection cited are linked where cited; each is dated 2026 and published by UVSM Publications, Wytheville, Virginia.

⁂

# APPENDICES

**How to read the appendices.** Each register in these appendices is reprinted whole, as it was fixed on 4 November 2026. Each register quotes in full every sealed prediction that it compares, so the same sealed sentence recurs from register to register. The sealed record is reproduced whole in Volume One, as its Appendix B, and a reader who knows the sealed record can pass over those quotations.

In the register tables, "agrees" in the column of standing means that measurement agrees with the collection's prediction, and not that the collection and the other account agree. Where a standing reads "agrees, for the collection; the difference is untested", the first part gives the standing of the collection's prediction, and the second part gives the standing of the difference between the collection and the other account.

A prediction filed "outside the sealed record" is stated in a relation essay or in a register, and it is not among the forty-two predictions sealed on 1 November 2026. A relation essay is a chapter of this book that sets one model beside the collection.

**Terms of the sealed record.** The "count route" and the "Koide route" of Prediction 38 are the two ways in which the collection's book *The Measures of the Kinds* places the neutrino masses. The count route places the masses from the measured mass of the tau alone and predicts both splittings, and the Koide route takes both splittings as inputs. The "carry family" and the "segment family" of Prediction 39 are the two families of lepton mixing in *The Measures of the Kinds*. The carry family puts the lepton phase in the fourth quadrant, and the segment family puts it in the third quadrant. The "second closure" and the "carriers' law" of Prediction 42 are laws of *The Strengths of the Kinds* (Chapter 3, Section VI, and Chapter 5) that give the strength of color and the masses of the W and Z bosons. The letter k names two quantities. In Prediction 17, k is the curvature of the internal dimensions in Planck units, which both observables of that prediction will find equal to 1. In Prediction 42, k is the second-order coefficient of the span from the electron to the reduced Planck mass, 3.7160.

**Figures in the sealed text, as later published.** The sealed text is not revised, and so the published figures below are carried to the next dated report. Under Prediction 10, the published targets are about one part in a thousand for LiteBIRD and about three parts in a thousand for the Simons Observatory. Under Prediction 7, the distance of $73.04 \pm 1.04$ from 67.8 is 5.0 standard deviations in units of the measurement's own uncertainty and 4.8 with the prediction's added in quadrature. Under Prediction 17, the two values within the DESI analyses differ by 4.6 standard deviations: $1.26 \pm 0.06$ and $0.68 \pm 0.11$.

Appendix A

# The Prediction Matrix

*The Registered Predictions of Physics from Comparison, Set Beside the Accounts of This Volume*

The table below takes the forty-two predictions registered on 1 November 2026 in *The Registered Predictions of Physics from Comparison* (reproduced whole in Volume One, Appendix B). I call The Registered Predictions of Physics from Comparison the sealed record. The table gives the predictions in the order and under the short titles that the sealed record gives them. For each prediction, the table names the accounts of this volume that address it. The accounts of this volume are those of Julian Barbour, Lee Smolin, Ilya Prigogine, Robert Rosen, Giulio Tononi and Karl Friston. Each of those accounts has its own chapter in this volume, and each chapter sets one account beside physics from comparison, the physics of the Immanent Metaphysics.

Each person named above has a register, a table that sets the predictions of that person's account beside the sealed record. In each register, and in this table, the two accounts compared are that person's account and the collection. The collection is the set of books in which physics from comparison is set out. A name under "Differs" means that the person's register files the entry where the two accounts differ. An entry filed where the two accounts differ sets the sealed prediction against one of two things. One is a different prediction of that person's own; the other is an account that states no prediction where the collection states one, as in Verlinde 1, 5 and 6, in Volume Five. A name under "Agrees" means that the register records the two accounts predicting the same finding. The number after a name is the number of the entry in that person's register. The word "none" under "Differs" means that no register of this volume files an entry on the prediction where the two accounts differ. The word

“none” under “Agrees” means that no register of this volume records an account predicting the same finding as the collection. Where both columns read “none”, no account of this volume addresses the prediction.

The table shows only which accounts of this volume address each sealed prediction, and whether each such account differs from the collection or agrees with the collection on that prediction. The table does not show what measurement has found for each prediction, and the table leaves out the differences between the accounts that no measurement decides. Each person’s full register follows as an appendix of its own. A register gives the statement of each entry, the measurements reported for the entry and what decides the entry.

| No. | Sealed prediction | Differs | Agrees |
|---|---|---|---|
| 1 | Gravitation entangles two masses | none | none |
| 2 | Gravitation alone ends no superposition | none | Barbour 4 |
| 3 | Gravitation is not quantized | Barbour 1; Smolin 1 | none |
| 4 | Free fall is universal and nothing shields gravity | none | Barbour 3 |
| 5 | The arena has no least length, area or duration | Smolin 1, 2 | none |
| 6 | Gravitational waves have two polarizations and travel at the speed of light | none | Barbour 2 |
| 7 | The matter fraction is 0.311 | none | none |
| 8 | The equation of state of the vacuum energy is exactly −1 | none | none |
| 9 | Space is flat to the size of the primordial departures | none | none |

| No. | Sealed prediction | Differs | Agrees |
|---|---|---|---|
| 10 | No primordial gravitational waves | none | none |
| 11 | The primordial departures are adiabatic | none | none |
| 12 | The departures are one pattern across the whole sky | none | none |
| 13 | No long inflationary phase | none | none |
| 14 | The gravitational waves of an epoch, and their absence where others expect them | none | none |
| 15 | The excess of matter has one sign everywhere | none | none |
| 16 | The ratio of the dark matter to the ordinary matter is $6 - 2/\pi$ | none | none |
| 17 | The coefficient shared with the cosmological constant is 1 | none | none |
| 18 | The amplitude of clustering is 0.823 | none | none |
| 19 | The dark matter acts only through gravity | none | none |
| 20 | The dark matter does not decay | none | none |
| 21 | The dark matter is perfectly cold | none | none |
| 22 | The gyrations have about the Planck mass | none | none |
| 23 | No short loop exists anywhere in space | none | none |

| No. | Sealed prediction | Differs | Agrees |
|---|---|---|---|
| 24 | A galaxy feels the field of a larger one only through its tide | Smolin 4 | none |
| 25 | The statistics of quantum theory hold | Smolin 3 | Friston 1 |
| 26 | What is found of color, charge and spin | none | none |
| 27 | No signal faster than light, and none backward in time | none | Rosen 1 |
| 28 | No world is perfectly deterministic, and no process is perfectly reversible | none | Smolin 5; Prigogine 1 |
| 29 | A discrete rule shows itself to a fine enough measurement | Smolin 1 | none |
| 30 | No kind of particle beyond the closed list | none | none |
| 31 | Exactly three generations | none | none |
| 32 | The neutrinos are Dirac particles; no neutrinoless double beta decay | none | none |
| 33 | The proton does not decay | none | none |
| 34 | The strong force breaks no reversal; no axion | none | none |
| 35 | No new particle in any loop | none | none |
| 36 | The running of the couplings changes only at known masses | none | none |
| 37 | Ceilings and relations among the masses | none | none |

| No. | Sealed prediction | Differs | Agrees |
|---|---|---|---|
| 38 | The neutrino masses: two readings, decided by their sum | none | none |
| 39 | Lepton mixing: two families, decided by the quadrant of the lepton phase | none | none |
| 40 | The mass of the tau: two readings | none | none |
| 41 | The quark unitarity triangle has a right angle | none | none |
| 42 | The strength of color, the W and Z, the Higgs and the top | none | none |

## Entries that rest on no sealed prediction

The entries listed below belong to the registers of this volume. Each of the entries below rests on an argument in the books of the collection, or on a statement in a relation essay, and on no prediction of the sealed record. A relation essay is a chapter of this book that sets one person's account beside the collection. The registers cite the chapters of the six volumes as relation essays. So none of the entries below appears in a row of the table above, which has one row for each sealed prediction.

- *Prigogine 2.* The pattern taken at a branching point is not fixed in advance. (Prigogine's register files Prigogine 2 among the predictions outside the sealed record. Only the relation essay on Prigogine states the prediction.)
- *Tononi 1.* The brain operates near criticality. (Tononi's register files Tononi 1 among the predictions outside the sealed record. The books of the collection argue the collection's prediction in Tononi 1, and the sealed record does not carry the prediction.)

- *Tononi.* The statement of the relation essay. (Tononi's register files the statement among the predictions outside the sealed record. The statement appears only in the relation essay on Tononi. The register says that the statement is not a prediction, and the register does not make the statement one.)

Appendix B

# The Registered Predictions Beside Julian Barbour

*A Dated Record, 4 November 2026*

Date of record: 4 November 2026. This record is fixed at its date of 4 November 2026 and is not revised, and a later report will carry a date of its own. This record sets the predictions of physics from comparison, the physics of the Immanent Metaphysics, beside the predictions of the physicist Julian Barbour. This record draws on two sources. The first source is *The Registered Predictions of Physics from Comparison; A Dated Record, 1 November 2026* (DOI https://doi.org/10.67291/RQQS3025), which is not revised; I call that dated record the sealed record. The second source is the relation essay *Janus and the Turn; Julian Barbour, the Arrow of Time and Physics from Comparison*, the chapter of this volume that sets Barbour's account beside physics from comparison.

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## Abstract

In this record, the collection is the set of books in which I set out physics from comparison, the physics of the Immanent Metaphysics. Julian Barbour and the collection agree with each other on more than either agrees with the usual account of time in physics. The two accounts are divided mostly over what time is, and no measurement decides the question of what time is. This record sets out, with its date, the places where the two accounts make claims that measurement can test. A registered prediction is a prediction that the collection registered in the sealed record on 1 November 2026. Three of the collection's registered predictions are predictions that Barbour's work also makes: gravitational waves travel at the

speed of light, which Barbour and his colleagues derived from best matching in 2002; free fall is universal; and no superposition ends through gravitation alone. Each of the three predictions agrees with every measurement made. One registered prediction parts from Barbour's account: the collection holds that gravitation is not quantized, while Barbour's timeless quantum universe is a wave function over configurations that include the geometry of space. No experiment now proposed separates the two accounts on that prediction, and this record says so. Five further differences are differences of kind: whether time is real, how the timeless equation of quantum gravity is to be read, what the Janus point and the turn are, what the laws must contain for time to have a direction, and what lies at the end of a black-hole interior. Barbour's Janus point is the configuration of least complexity from which complexity grows in both directions, and the collection's turn is the passage from the end of one epoch of the universe to the beginning of the next. This record names each difference of kind and the kind of claim it is, and the record invents no test for any of the five.

## I. What This Record Is

This record sets the registered predictions of physics from comparison beside the claims of Julian Barbour's physics: the dynamics of best matching that he built with Bruno Bertotti (1982), his account of time in *The End of Time* (1999), the gravitational arrow of time that he found with Tim Koslowski and Flavio Mercati (2014), and the development of that arrow of time in *The Janus Point* (2020). Best matching is Barbour and Bertotti's method of comparing two configurations by shifting and turning one against the other until their difference is least, and of building dynamics from what remains. This record takes the collection's predictions from the sealed record of 1 November 2026, and it quotes each prediction in full, with the number that the prediction has in the sealed record. This record takes Barbour's claims from his own works, and it cites the work at each entry.

The sealed record fixes what counts as a result: "A result counts when it is established at five standard deviations by at least two independent kinds of measurement". A measurement that falls short of that standard is a measurement of interest. A book of the collection argues every prediction of the collection that this record states, and this record names that book at its chapter and section. No prediction in this record is stated only in the relation essay.

This record belongs to a book that sets accounts of the universe side by side and looks back on them, and so the dates of the work are part of the comparison. I formulated the first axiom of the Immanent Metaphysics in or before 1991, and I formulated the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996. I did most of my work in physics in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1. The Incommensuration Theorem states that symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison, and that neither can asymmetry and discontinuity. The Incommensuration Theorem is a structural fact about the nature of knowing. Barbour's best matching dates from 1982, and his account of timelessness dates from 1999; this record credits each result to Barbour at its date.

## II. Where the Two Accounts Predict Differently

### Barbour 1. Whether the geometry of space carries quantum degrees of freedom of its own

**The collection predicts.** "No effect will show the geometry carrying quantum degrees of freedom of its own, beyond those tied to the alternatives of the matter. A description of the small waves of the geometry by quanta holds below the Planck curvature, and its quanta are quanta of that description, never quanta of the arena. No measured cross section for

the scattering of those waves that departs from the effective theory will agree with a calculation in which the metric is quantized beyond it. A detector that registers a gravitational wave in single clicks agrees with the account and does not show gravitation quantized". The collection registered this prediction on 1 November 2026 as Prediction 3 of The Registered Predictions of Physics from Comparison.

**Barbour predicts.** Barbour holds that the universe as a whole is quantum. In *The End of Time* (1999) the state of the universe is a wave function on Platonia, which is Barbour's name for the space of all configurations of the universe. For a universe governed by Einstein's theory of gravitation, general relativity, those configurations include the geometry of space. The equation that governs Barbour's wave function is of the same kind as the Wheeler-DeWitt equation of canonical quantum gravity, which is the quantization of general relativity in which the geometry of space is the configuration variable. The Wheeler-DeWitt equation has no time in it, and Barbour writes that "quantum cosmology will have no dynamics. It will be timeless" (1999). On Barbour's account the geometry of space carries quantum degrees of freedom of its own, as every configuration variable of a quantum universe does.

**Where argued.** The Unquantized Arena, Chapter 19, Section III (Prediction 19.2), and Chapter 9, Section III; The Gravitational Passage, Chapter 12, Questions; The Branches of the Kinds, Chapter 4, Section III. The arena is the context of physics, the geometry of space and time within which content is found. The reading of the Wheeler-DeWitt equation as the arena put into the quantum state is in The Unquantized Arena, Chapter 6.

**Measured.** The sealed record reports the measurements in these words: "The first gravitational wave detected matched the classical waveform of general relativity (Abbott and others 2016); no graviton has been detected".

**What decides it.** The sealed record names no coming measurement that would decide Prediction 3. The Planck curvature is the curvature whose radius is the Planck length, the scale at which an object's gravitational size equals its quantum size, and the Planck curvature is not a least length. The effective field theory of gravity is the description of the small waves of the geometry by quanta, valid below the Planck curvature. In its Section IX the sealed record states that below the Planck curvature the collection and the effective field theory of gravity give the same result for every experiment now proposed, and that a detection of single gravitons would not show gravitation quantized. A finding that decides between the two accounts would be a finding that shows the geometry carrying quantum degrees of freedom beyond those tied to the alternatives of the matter, and the collection predicts that no such finding will ever be made. The collection predicts that gravitation entangles two masses (Prediction 1), but that entanglement does not decide between the two accounts, because a quantized geometry predicts the same phase.

Barbour, Maria Lourenço and Francisco Lobo have recently related the clustering of bodies in the Newtonian problem of many bodies to the filaments of the cosmic web (Lourenço, Barbour and Lobo 2026; Barbour, Lobo and Lourenço 2026). Their work states no measured quantity, so this record sets no entry beside the collection's predictions of the primordial departures and of the amplitude of clustering (Predictions 12 and 18). A comparison of predictions needs a number, or a kind of finding, from each side.

## III. Where the Two Accounts Agree

### Barbour 2. Gravitational waves travel at the speed of light

**The collection predicts.** "Gravitational waves carry the two polarizations of a massless field of spin two, and travel at the speed of light; no further polarization and no other speed will be found". The collection registered this prediction on 1 November 2026 as Prediction 6 of The Registered Predictions of Physics from Comparison.

**Barbour predicts.** Barbour, Brendan Foster and Niall Ó Murchadha derived from best matching, in 2002, that every scalar field and every vector field that best matching treats must share the characteristic speed of gravity. In their words: "Thus Einstein causality emerges". The result of Barbour, Foster and Ó Murchadha came from Barbour's program. In this record I credit that result to Barbour's program at the date of the result, 2002. The work of Barbour, Foster and Ó Murchadha fixes the speed of gravitational waves but does not take up the count of polarizations, so Barbour's account and the collection agree on the speed.

**Where argued.** The Gravitational Passage, Chapter 12, Section VII, and Chapter 16, Section V; The Unquantized Arena, Chapter 19, Section V; The Compactification, Chapter 7, Section II.

**Measured.** The sealed record reports the measurements in these words: "The three-detector event GW170814 favors purely tensor polarization; GW170817 with its gamma-ray burst bounds the difference between the speed of gravitational waves and the speed of light to between $-3 \times 10^{-15}$ and $+7 \times 10^{-16}$ of the speed of light (Abbott and others 2017)".

### Barbour 3. Free fall is universal

**The collection predicts.** "The Eötvös parameter, the fractional difference in the free fall of two materials, is zero for every pair of materials at every precision. Antimatter falls with the acceleration of matter. No arrangement of matter shields gravity, and nothing will be found that gravity

leaves untouched". The collection registered this prediction on 1 November 2026 as Prediction 4 of The Registered Predictions of Physics from Comparison.

**Barbour predicts.** General relativity fits the pattern of best matching, given the thin-sandwich conjecture (Barbour and Bertotti 1982), which is the conjecture that two nearby geometries of space fix the history between them. Later, Barbour, Foster and Ó Murchadha derived general relativity from a relational starting point of the same kind as best matching (Barbour, Foster and Ó Murchadha 2002). In general relativity free fall is universal and nothing shields gravity. Barbour, Foster and Ó Murchadha (2002) found that self-consistency requires of any field of the vector kind "Einstein causality, the equivalence principle" and the Gauss constraint. The equivalence principle is the principle that every body and every field responds to gravity in the same way, so that free fall is universal.

**Where argued.** The Unquantized Arena, Chapter 19, Section IV (Prediction 19.3); Two Theories, One World, Chapter 9.

**Measured.** The sealed record reports three measurements. The MICROSCOPE experiment compared the free fall of titanium and platinum and found an Eötvös parameter of $[-1.5 \pm 2.3$ (statistical) $\pm 1.5$ (systematic)$] \times 10^{-15}$ (Touboul and others 2022). The ALPHA-g experiment found that antihydrogen falls toward the Earth at $(0.75 \pm 0.13 \pm 0.16)$ g, where g is the acceleration of ordinary matter in free fall at the Earth's surface (ALPHA-g, Anderson and others 2023). No shielding of gravity was found, with an absorption coefficient of $(3 \pm 5) \times 10^{-23}$ cm$^2$ g$^{-1}$ (Williams, Turyshev and Boggs 2009).

### Barbour 4. Gravitation alone ends no superposition

**The collection predicts.** "No mass, however large, no separation of two placements, however wide, and no length of time ends a superposition of its own accord; a superposition ends only through a finding, an interaction that registers which alternative is the case. The account allows no decoherence beyond the ordinary kind, which is a comparison made by

some environment. For the masses of Prediction 1, the gravity-driven collapse of Diósi and Penrose gives a lifetime of about 0.012 seconds, against the 2.5 seconds the entangling phase needs". The collection registered this prediction on 1 November 2026 as Prediction 2 of The Registered Predictions of Physics from Comparison.

**Barbour predicts.** A superposition is a quantum state that is a sum of alternatives, each with a complex weight. A collapse is an ending of a superposition proposed as a new physical process, as in the model of Diósi and Penrose, in which gravity itself ends the superposition. Barbour's quantum universe has no collapse. In *The End of Time* (1999) Barbour reads quantum theory in a way of the many-worlds kind. In that book Barbour draws on the physicist John Bell's paper "Quantum mechanics for cosmologists" (1981), and Barbour finds Bell's account close to his own in all but its view of time. Nothing in Barbour's account ends a superposition through gravitation. The two accounts part on whether a superposition ends at all, since in a reading of the many-worlds kind no superposition ends. The two accounts agree that gravitation alone ends no superposition.

**Where argued.** The Unquantized Arena, Chapter 7, Sections V and VI, and Chapter 8, Section IV.

**Measured.** The sealed record reports the measurements in these words: "An underground search for the radiation that collapse noise would make has ruled out the version of the Diósi and Penrose model with no free parameter (Donadi and others 2021); versions with a larger effective size remain under test".

A claim of kind is a claim about what a thing is, or about what a law must hold, and not a claim about what a finding will be. The two accounts also agree on four claims of kind that no measurement decides, and Section V sets those claims beside the differences. The four shared claims of kind are these: inertia is a comparison, and a frame is a frame only

through content there to compare against; time is not a container given before the happenings in it; the arrow of time does not wait on a special condition placed at a beginning; and every record is a record of the past.

## IV. Predictions Stated Only in the Relation Essay

The relation essay states only predictions that the books of the collection argue or that the sealed record carries, so no prediction belongs in this section.

## V. Where No Measurement Decides

Each difference in this section concerns what a thing is, what form a law must take, or what the act of knowing contains. A measurement is itself an act of comparison, and both accounts read every finding alike: both read the same positions, the same records and the same clocks. Where two accounts agree on every finding but part on what findings are, or on what a law must hold, no finding chooses between the two accounts. Falsification is the refutation of a claim by a finding that contradicts the claim. Falsification applies to claims about what findings will be. Falsification does not apply to the differences of this section, and this record invents no test for those differences.

### Whether time is real

The two claims about whether time is real are descriptions of what a thing is. Barbour holds that the universe consists of instants, each instant a complete configuration, and that time as something flowing is an illusion carried by time capsules (1999). In Barbour's account a time capsule is a structure within one instant that encodes a history. The collection holds that "A law exists; a measurement is real", and that what exists, laid out as structure, and what is real, given in an actual act of comparison, each need the other (Comparison, Chapter 10, Section II). The collection also

holds that time is one triple of geometric time, event time and evolution time (Measurement, Chapter 12, Section III). Geometric time is time laid out as one structure in the metric. Event time is the order of findings, and evolution time is the parameter of the smooth evolution of a quantum state. When a measurement bears on whether time is real, the measurement is an act of comparison that leaves a record, and Barbour reads that record as a time capsule within one instant. No finding separates Barbour's reading of that record from the collection's reading of it, because both readings are readings of the same record.

**The timeless equation**

The two readings of the timeless equation are claims of logical form. Barbour took the absence of time from the Wheeler-DeWitt equation as support for a world without time. The collection reads the absence of time from that equation as the product of a category error. The collection states the error in these words: "The context in which things happen has been put into the quantum state, instead of serving as the arena in which the state evolves" (The Unquantized Arena, Chapter 6). Measurement can test one side of this difference: the side set out in entry Barbour 1 of this record. The reading of the equation itself is not measured.

**The Janus point and the turn**

On the Janus point and the turn, the two accounts give descriptions of what a thing is. Barbour's Janus point is the configuration of least complexity within one solution of the gravitational problem of many bodies. Complexity grows from the Janus point in both directions, so observers on either side have their past toward the Janus point (Barbour, Koslowski and Mercati 2014; Barbour 2020). The collection's turn is the passage from the end of one epoch to the beginning of the next, at the end of the black-hole interiors. An epoch is one stage in the cycle of the universe, from one turn to the next. No comparison registers the turn as an event, and the cycle of epochs has no first turn (The Compactification, Chapter 1, Section

V). The Janus point and the turn are alike in this respect: each is the point from which an arrow of time runs, in a state of least structure. For Barbour that point is the configuration of least complexity. For the collection that point is the passage between epochs, after which the new epoch begins even, with no clumping of its geometry carried from before, up to the small departures that the Incommensuration Theorem requires (The Compactification, Chapter 3, Section VI). No observer has a record of the far side of the Janus point or of the turn: Barbour's observers see only the records of their own half, and the collection's new epoch carries no record of the epoch before it. Neither account computes a finding on the far side, and the sealed record states that the dynamics of the transition between epochs are not computed (Section VI of this record, below).

**What the laws must contain for time to have a direction**

The two claims about what the laws must contain are claims of logical form, about what a law must hold. Barbour's account needs no asymmetry of time in the laws, because his model law treats past and future alike, and the arrow of time comes from the solution of that law (Barbour, Koslowski and Mercati 2014). The collection holds that the arrow of time is present in a single comparison, and that some asymmetry of time must exist in the laws. The sealed record states: "No superdeterministic completion of quantum mechanics will be found, and no world is purely and completely deterministic. Some asymmetry of time must exist in the laws, and no process at any scale is perfectly reversible; a reversal of evolution, by an inverse in a formalism or by a pulse in a laboratory, does not remove a finding from the order of findings. These are exclusions that the structure of comparison makes; the outcome of a search for departures from the quantum predictions bears on Prediction 25 and not on this one". The collection registered this prediction on 1 November 2026 as Prediction 28 of The Registered Predictions of Physics from Comparison. The collection argues Prediction 28 in The Basis of Physics, Essays 9 and 11; Measurement, Chapter 14, Sections II and III; Why Time Travel Is Not a Concept,

Chapter 5, Sections III to V. CP is the combined reversal of charge and of left and right. The sealed record reports the measurements that bear on the asymmetry of time: "Violations of CP (1964) and of time reversal (CPLEAR 1998; BaBar 2012) are consistent with the required asymmetry". The measured violations are what the collection requires. Barbour's model neither requires the violations nor is troubled by the violations, since Barbour asks of his model only that a law symmetric in time be enough for an arrow of time. The two accounts part on what a law must hold. Neither a measured violation nor a measured absence of a violation can settle what a law must hold.

**The end of a black-hole interior**

On the end of a black-hole interior, the two accounts give descriptions of what a thing is. Shape dynamics is a reformulation of general relativity in which only the shapes of configurations carry physical meaning. Barbour founded the program of shape dynamics and developed it with Henrique Gomes, Sean Gryb and Tim Koslowski. In shape dynamics a black hole corresponds to a spherically symmetric solution that is a wormhole with no singularity, and on that solution shape dynamics and general relativity part (Gomes 2014). In shape dynamics the big bang of a simple cosmological model is a regular point of the relational evolution, and the relational evolution continues through that big bang (Koslowski, Mercati and Sloan 2018). On the collection's account the six internal dimensions make up a complex projective plane together with a sphere, held compact, and nothing travels through them. The collection holds that at the end of every black-hole interior the conditions that hold the six internal dimensions compact fail, and the ten-dimensional geometry restores a context, which is the Big Bang of the next epoch (The Compactification, Chapter 1, Section V; At the Edge of Reality, Chapter 13). Outside the horizon of a black hole, both accounts agree with general relativity. Within the horizon, no finding returns to an observer outside.

## VI. What the Collection Does Not Predict Here

Section IX of the sealed record holds four items that bear on this comparison, and this record quotes the four items in full.

> "The size of the asymmetry of time is not predicted, only that it exists (The Basis of Physics, Essay 11, Section VII)".
>
> "The dynamics of the transition between epochs, and how the gyrations are made at the turn, are not computed (The Weight of Possibility, Chapter 6)".
>
> "Below the Planck curvature the account and the effective field theory of gravity give the same result for every experiment now proposed (The Unquantized Arena, Chapter 6, Section IV); a detection of single gravitons, or of a primordial background, would not show gravitation quantized (Chapter 9, Section III; Chapter 18, Section VI)".
>
> "The account asserts neither the return of the information that falls into a black hole formed from a star to the outside world, nor its loss to it (The Unquantized Arena, Chapter 17, Section VII); on the account of The Gravitational Passage that information is not destroyed, and re-emerges in the initial conditions of the next epoch (Chapter 18, Section XIII)".

The first of the four quoted items bears on the arrow of time. Barbour also gives no size for the asymmetry of time, since he sets no asymmetry in the law. The second item bears on the turn, which Section V sets beside the Janus point. The third item bears on entry Barbour 1. The fourth item bears on the end of a black-hole interior.

## VII. The Record at Its Date

| Entry | The collection | Barbour | Measured | Standing |
|---|---|---|---|---|
| Barbour 1 (Prediction 3) | The geometry carries no quantum degrees of freedom of its own | A quantum universe; the geometry among the quantized configurations | Classical waveform; no graviton detected | Agrees, for the collection; the difference is untested, and no experiment now proposed reaches it |
| Barbour 2 (Prediction 6) | Two polarizations; speed of light | Speed of light (2002) | Tensor favored; speed within $10^{-15}$ | Agrees |
| Barbour 3 (Prediction 4) | Universal free fall; no shield | General relativity recovered; the equivalence principle required | $[-1.5 \pm 2.3 \pm 1.5] \times 10^{-15}$ | Agrees |
| Barbour 4 (Prediction 2) | No collapse or decoherence from gravity alone | No collapse | The version of the Diósi and Penrose model with no free parameter ruled out | Agrees as far as tested |

## Summary

Julian Barbour and the collection agree on most of what can be measured on the questions that both of their accounts address. Barbour and the collection both hold three things: gravitational waves travel at the speed of light, which Barbour and his colleagues derived from best matching in

2002; free fall is universal; and no superposition ends through gravitation alone. Each of the three is a registered prediction of the collection, and each agrees with every measurement made. Where a measurement could in principle decide between the two accounts, they part on one registered prediction. The collection holds that the geometry of space carries no quantum degrees of freedom of its own, while Barbour's quantum universe is a wave function over configurations that include the geometry of space. No experiment now proposed separates the two accounts on that prediction, and the sealed record says so. The rest of what divides the two accounts is a difference of kind: whether time is real, how the timeless equation is to be read, what the Janus point and the turn are, what the laws must hold for time to have a direction, and what ends a black-hole interior. For each difference of kind, this record names the kind of claim it is. The two accounts also share claims of kind: inertia is a comparison, the arrow of time does not wait on a special beginning, and every record is a record of the past.

**Key Concepts**

- The rule of decision: a result counts when it is established at five standard deviations by at least two independent kinds of measurement.
- Three registered predictions, Predictions 2, 4 and 6, are shared with Barbour's account, and each of the three agrees with every measurement made.
- One registered prediction, Prediction 3, parts from Barbour's quantum universe, and no experiment now proposed separates the two accounts on Prediction 3.
- Barbour and his colleagues derived the shared speed of gravity and light from best matching in 2002.
- Two differences of kind are whether time is real and what the Janus point and the turn are, and no finding chooses between the two accounts on either difference.
- The measured violations of time reversal are what the collection requires, while Barbour asks of his model only that a law symmetric in time be enough for an arrow of time.

## Terms

**Arena.** The context of physics, the geometry of space and time within which content is found; on the collection's account, what gravitation is.

**Best matching.** Barbour and Bertotti's method of comparing two configurations by shifting and turning one against the other until their difference is least, and building dynamics from what remains.

**Canonical quantum gravity.** The quantization of general relativity in which the geometry of space is the configuration variable; its central equation is the Wheeler-DeWitt equation.

**Collapse.** An ending of a superposition proposed as a new physical process, as in the model of Diósi and Penrose, in which gravity itself ends it.

**Effective field theory of gravity.** The description of small waves of the geometry by quanta, valid below the Planck curvature.

**Equivalence principle.** The principle that every body and every field responds to gravity in the same way, so that free fall is universal.

**Eötvös parameter.** The fractional difference between the accelerations of two bodies of different composition in free fall.

**Event time, evolution time, geometric time.** The order of findings; the parameter of the smooth evolution of a quantum state; time laid out as one structure in the metric. The collection holds the three as one triple.

**Epoch.** One stage in the cycle of the universe, from one turn to the next.

**Exist and real.** To exist is to stand as structure, timeless and laid out; to be real is to be given in an actual act of comparison, now.

**Gyration.** The unit of the dark matter on the collection's account: a conserved excitation of the six held internal dimensions, of about the Planck mass.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Janus point.** In Barbour's account, the configuration of least complexity in a typical solution of the gravitational problem of many bodies, from which complexity grows in both directions.

**Planck curvature.** The curvature whose radius is the Planck length, the scale at which an object's gravitational size equals the object's quantum size; the Planck length is not a least length.

**Platonia.** Barbour's name for the space of all possible configurations of the universe.

**Rule of decision.** The rule of the registered predictions: a result counts when it is established at five standard deviations by at least two independent kinds of measurement.

**Shape dynamics.** A reformulation of general relativity, developed in Barbour's program, in which only the shapes of configurations carry physical meaning.

**Six internal dimensions.** The internal space $\mathbb{C}P^2 \times S^2$, a complex projective plane and a sphere, held compact; on the collection's account they are the range from which each finding is one selection, and nothing travels through them.

**Superposition.** A quantum state that is a sum of alternatives, each with a complex weight.

**Time capsule.** In Barbour's account, a structure within one instant, such as a fossil or a record, that encodes a coherent history.

**Turn.** The passage from the end of one epoch of the universe to the beginning of the next, at the end of every black-hole interior; no comparison registers it as an event.

**Wheeler-DeWitt equation.** The central equation of canonical quantum gravity, an equation that contains no time parameter.

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Appendix C

# The Registered Predictions Beside Lee Smolin

*A Dated Record, 4 November 2026*

Date of record: 4 November 2026. This record is fixed at its date and is not revised; a later report will carry its own date. This record sets the predictions of physics from comparison, the physics of the Immanent Metaphysics, beside the predictions of the physicist Lee Smolin. The record draws on two works of mine. The first work is *The Registered Predictions of Physics from Comparison; A Dated Record, 1 November 2026* (DOI https://doi.org/10.67291/RQQS3025), which stands as it is, because I fixed its wording on its date and do not revise it. The second work is the relation essay *Time Is Real; Lee Smolin and Physics from Comparison*, the essay in which I relate Smolin's work to physics from comparison.
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## Abstract

Lee Smolin's work makes predictions on four fronts that a measurement could test in principle: the discrete values that area and volume take in loop quantum gravity, the program of quantum gravity that he helped to found; a dependence of the speed of light on the energy of the light at the Planck scale (the scale of the Planck energy, which Newton's constant, the speed of light and the reduced Planck constant fix), a dependence that his work holds open as a possibility and sets out how to find; departures from the statistics of quantum mechanics for states that have few copies in the universe, or that have no precedent (no earlier instance of the same measurement); and the motions of galaxies at low acceleration, which he reads as a regime of quantum gravity. On each of the four

fronts, the physics collection of the Immanent Metaphysics makes a prediction that differs from Smolin's. I registered the collection's predictions on those fronts on 1 November 2026: the arena (the geometry of space and time within which content is found) has no least length, area or duration, and light of every energy travels at one speed (Prediction 5); repeated measurements settle to the weights of the Born rule in every sector (Prediction 25); and a galaxy feels the field of a larger one only through its tide (Prediction 24). On the speed of light, the timing of light from distant bursts agrees with the collection, because the timing places any dependence of the first order (a change in the speed of light in simple proportion to the energy of the light) above about ten times the Planck energy. On the statistics of quantum mechanics, every test of the Born weights so far agrees with the collection. Two fronts are not yet decided by the rule of decision: the discrete values of area and volume, and the motions of galaxies. The rule of decision is the rule by which a result counts when it is established at five standard deviations by at least two independent kinds of measurement. Smolin's account and the collection agree that some asymmetry of time is in the laws (Prediction 28). The deepest differences between the two accounts are differences of kind, which no measurement can test: whether the laws change, whether universes form a population that inherits its constants, and whether time is prior to space. This record names each of those differences as a difference of kind. Smolin predicts a ceiling on the mass of neutron stars, while the collection makes no prediction about that mass. This record states Smolin's prediction of the ceiling, with the measurement that bears on it, and counts the prediction neither for nor against the collection.

## I. What This Record Is

This record sets two bodies of prediction side by side: the predictions of my books of physics from comparison, as the sealed record of 1 November 2026 states them, and the predictions of Lee Smolin's program, as his own papers and books state them. The sealed record is *The Registered Predic-*

*tions of Physics from Comparison*, the register of predictions whose wording I fixed on that date and do not revise. Where the two bodies of prediction say different things about what a measurement will find, this record states both predictions, the measurement made so far, and the measurement that decides between them. Where the two bodies of prediction agree, this record says that they agree. Where they differ in a way that no measurement can test, this record names the kind of claim that each side makes.

This record uses the sealed record's rule of decision, which reads: "A result counts when it is established at five standard deviations by at least two independent kinds of measurement. A measurement that differs from a prediction by less is a measurement of interest, and the record reports it as such". A standard deviation is the measure of the uncertainty of a measurement. A difference of five standard deviations is the usual threshold for a discovery in physics.

Every prediction of the collection that this record states is argued in a book of the collection, which this record names at its chapter and section. The sealed record carries each of those predictions under its number. Section IV of this record is kept for any prediction that only the relation essay states, but the relation essay states no such prediction. The ground of the collection is the Incommensuration Theorem, with the three axioms that follow from it. The Incommensuration Theorem states that symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The Incommensuration Theorem is a structural fact about the nature of knowing. I formulated the first axiom in or before 1991, and the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996. I did most of my work in physics in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1.

## II. Where the Two Accounts Predict Differently

### Smolin 1. Discrete area and volume

**The collection predicts.** "The speed of light in vacuum does not depend on the energy of the light through any step of spacetime. No discrete spectrum of area or volume will be observed, in the echoes of gravitational waves from merging black holes or anywhere else. Discreteness belongs to the content, the charges and the kinds of particle, and the account predicts it there". I registered this prediction on 1 November 2026 as Prediction 5 of *The Registered Predictions of Physics from Comparison*. In the collection's terms, the content is what is found within the arena: the particles, their charges and their fields. I draw two further predictions from the same step of the collection's argument. "No effect will show the geometry carrying quantum degrees of freedom of its own, beyond those tied to the alternatives of the matter. A description of the small waves of the geometry by quanta holds below the Planck curvature, and its quanta are quanta of that description, never quanta of the arena. No measured cross section for the scattering of those waves that departs from the effective theory will agree with a calculation in which the metric is quantized beyond it. A detector that registers a gravitational wave in single clicks agrees with the account and does not show gravitation quantized". I registered this second prediction on 1 November 2026 as Prediction 3. "For any one fixed discrete rule offered as the foundation of physics, a sensitive enough measurement, reaching below the rule's least step, tells the rule's statistics from the world's. The established findings of physics are reproduced at the foundation only by a theory of the conjugate kind". I registered this third prediction on 1 November 2026 as Prediction 29.

**Smolin predicts.** Smolin helped to found loop quantum gravity, a program that quantizes the geometry of space without a fixed background. In loop quantum gravity the area of every surface and the volume of every region take separate, discrete values, which are labeled by spin networks (graphs whose edges and nodes carry labels of spin). The physicist Carlo

Rovelli and Smolin computed the spectra of area and volume (the lists of the discrete values that area and volume can take) in 1995. Rovelli and Smolin call the spectra predictions for hypothetical measurements of the geometry of space at the Planck scale (Rovelli and Smolin 1995). On the program of loop quantum gravity, the geometry of space carries quantum degrees of freedom of its own.

**Where argued.** The Unquantized Arena, Chapter 19, Section V (Prediction 19.4), and Chapter 6, Section IV (Proposition 6.3); Two Theories, One World, Chapter 27; Incommensuration, Chapter 5, Section III. For Prediction 3: The Unquantized Arena, Chapter 19, Section III (Prediction 19.2), and Chapter 9, Section III; The Gravitational Passage, Chapter 12, Questions; The Branches of the Kinds, Chapter 4, Section III. For Prediction 29: The Unquantized Arena, Chapter 3, Sections II and VI; The Basis of Physics, Essay 18, Section VII; Measurement, Chapter 8, Section VIII. *The Unquantized Arena* replies to loop quantum gravity at the premise on which the program rests, in Chapter 4, Section III: "The spectra are spectra of operators defined after the arena has been quantized". So the discrete values of area and volume follow only once the arena is taken to be quantized. The collection holds that the arena is not quantized.

**Measured.** The first gravitational wave detected matched the classical waveform of general relativity. No graviton (the particle that a quantized theory of gravitation posits) has been detected (Abbott and others 2016, as the sealed record reports). No one has reported an observation of a discrete spectrum of area or volume.

**What decides it.** The measurement that decides is, in the sealed record's words, "every observation of the spectrum of area or volume". The sealed record also states the range in which the decision lies: "Below the Planck curvature the account and the effective field theory of gravity give the same result for every experiment now proposed". The Planck curvature is the curvature whose radius is the Planck length, the scale at which an object's gravitational size equals its quantum size. The Planck curvature is not a least length. The effective field theory of gravity is the description of small waves of the geometry by quanta, valid below the

Planck curvature. So the two accounts are separated by a measurement of geometry that reaches the Planck scale, and not by any experiment now proposed.

### Smolin 2. The speed of light at every energy

**The collection predicts.** "The speed of light in vacuum does not depend on the energy of the light through any step of spacetime. No discrete spectrum of area or volume will be observed, in the echoes of gravitational waves from merging black holes or anywhere else. Discreteness belongs to the content, the charges and the kinds of particle, and the account predicts it there". I registered this prediction on 1 November 2026 as Prediction 5 of *The Registered Predictions of Physics from Comparison*.

**Smolin predicts.** Smolin's work holds open the possibility that the speed of light depends on the energy of the light at the Planck scale, through a broken or deformed symmetry of spacetime. His work also sets out how to find a dependence of that kind. Smolin and the physicist Giovanni Amelino-Camelia examined how the highest-energy photons that the Fermi telescope records from gamma-ray bursts can measure such a dependence or bound it. The two physicists proposed bounds that assume little about the sources of the bursts. They also proposed a search for photons and neutrinos of still higher energy from the bursts, whose arrival would be delayed or advanced by days to months (Amelino-Camelia and Smolin 2009). In many models of a granular arena (an arena made of least steps), light of different energies travels at different speeds. The collection predicts that light of every energy travels at one speed.

**Where argued.** The Unquantized Arena, Chapter 19, Section V (Prediction 19.4), and Chapter 6, Section IV; Two Theories, One World, Chapter 27; Incommensuration, Chapter 5, Section III.

**Measured.** A photon of 31 GeV, which the Fermi telescope recorded from the burst GRB 090510, put the energy at which a dependence of the first order would appear above 1.2 times the Planck energy (Abdo and others 2009). A dependence of the first order is one in which the change in

the speed of light grows in simple proportion to the energy of the light. High-energy photons from the gamma-ray burst GRB 221009A arrived at times that place any energy dependence of the first order above about ten times the Planck energy (the Large High Altitude Air Shower Observatory, LHAASO; Cao and others 2024). Both measurements are of one kind, the timing of photons from bursts. No one has found a dependence of the speed of light on its energy.

**What decides it.** The measurement that decides is, in the sealed record's words, "The timing of photons of different energies from many sources, told apart from effects at the source by its growth with distance". Amelino-Camelia and Smolin proposed a search for high-energy neutrinos from bursts. Those neutrinos would give a second, independent kind of measurement, which a result needs under the rule of decision.

### Smolin 3. Quantum statistics for states without precedent

**The collection predicts.** "Repeated measurements on identically prepared systems settle to the weights of the Born rule, in every sector and on the full space, including in the tests proposed for superdeterminism, which look for departures from those weights. The interference among three paths has no term that the pairs of paths do not account for. Tests of the CHSH inequality reach $2\sqrt{2}$ and go no further, and stay at 2 or below whenever either party's two observables commute. Experiments with independent sources find the complex, not the real, composition of independent systems". I registered this prediction on 1 November 2026 as Prediction 25 of *The Registered Predictions of Physics from Comparison*. The Born rule is the rule that the probability of a finding is the square of the magnitude of its amplitude. Superdeterminism is a deterministic completion of quantum mechanics in which the settings of an experiment are fixed together with the states of what is measured, so that statistical independence fails. The CHSH inequality is the inequality of Clauser, Horne, Shimony and Holt, a sum of four correlations between two parties that is at most 2 for any local account of hidden variables.

**Smolin predicts.** Smolin seeks a realist completion of quantum mechanics. Two of his proposals say where the statistics of quantum mechanics would fail. In his real ensemble formulation, the ensemble that a quantum state describes is the set of all systems in the universe that are in that state. The real ensemble formulation implies departures from quantum mechanics for systems in states that can be expected to have few copies in the universe (Smolin 2012a). His second proposal is the principle of precedence, on which "the outcome of a measurement on a quantum system is selected randomly from the ensemble of outcomes of previous instances of the same measurement on the same quantum system". On the principle of precedence a system with no precedent is not bound by any prior law. Smolin names the test of the principle: to construct new entangled states and study their evolution (Smolin 2012b, Section 4). Entangled states are states of two or more systems that are linked, so that no one of the systems can be described on its own.

**Where argued.** The Quantum Passage, Chapters 5, 7 and 8, and Appendix B; The Unquantized Arena, Chapter 13, Section VII.

**Measured.** Three-slit experiments find the third term consistent with zero (Sinha and others 2010), as the sealed record reports. The third term is the term of interference among three paths that the pairs of paths do not account for. The sealed record also reports that network experiments with independent sources in 2022 found the complex composition (Chen and others; Li and others). No experiment has reported a departure from the Born weights. The sources this record draws on report no experiment designed to compare states prepared for the first time with states prepared many times. Experimenters who sampled random circuits on a superconducting processor prepared states of many qubits (quantum bits) that had never been prepared before, and sampled each of those states many times (Arute and others 2019). On Smolin's principle the repetitions of each new state become precedents for the later repetitions, so such sampling measures the long-run weights of states without precedent and not their first outcomes, as the relation essay sets out (*Time Is Real*, Section IX).

**What decides it.** The measurement that decides is a series of repeated measurements on entangled states prepared for the first time, or held in few copies, at enough repetitions to resolve the Born weights. On such states the collection predicts the Born weights, as it does everywhere, while Smolin's proposals predict a departure from the Born weights. Neither account names a size for the departure, so the test is whether any departure at all is established by the rule of decision: Smolin's proposals predict a departure, and the collection predicts none.

### Smolin 4. Galaxies at low acceleration

**The collection predicts.** "A galaxy falling freely in the field of a larger one feels that field only through its tide; the external field effect that modified Newtonian dynamics predicts will not be found". I registered this prediction on 1 November 2026 as Prediction 24 of *The Registered Predictions of Physics from Comparison*. The tide is the difference in the pull of a distant body across an extended one. The tide is all of the distant body's field that a freely falling system feels. Modified Newtonian dynamics is the law of gravity of the physicist Mordehai Milgrom, which departs from Newton's law below a constant of acceleration. In the modified dynamics, the external field effect is the change in a galaxy's internal motions produced by the uniform field of a larger body that the galaxy falls in. General relativity has no such effect, only the tide.

**Smolin predicts.** Smolin proposes that the modified Newtonian dynamics of Mordehai Milgrom describes a regime of quantum gravity, which holds when the cosmological constant is small and positive, at temperatures below the de Sitter temperature (the temperature of the horizon of a universe with a positive cosmological constant) or lengths beyond the horizon. The cosmological constant is an energy of empty space that never changes. In Smolin's regime the equivalence principle in its usual form fails. The equivalence principle is the principle that gravitational and inertial mass are equal, so that bodies fall alike and a body falling freely carries its own physics with it. The equivalence principle is replaced in

Smolin's regime by a ratio of gravitational to inertial mass that depends on environmental and global parameters. In the limit in which quantum effects and the finite speed of light drop out, a ratio that depends on those parameters reproduces the modified dynamics (Smolin 2017). The two accounts part at a ratio that depends on the environment, because on the collection's account a galaxy feels its environment only through the tide.

**Where argued.** The Weight of Possibility, Chapter 5, Section V: "a galaxy falling freely in the field of a larger one feels that field only through its tide, as general relativity requires, and not through the external field effect that the modified dynamics predicts".

**Measured.** The wide binary stars that the Gaia satellite measured agree with the tide. A wide binary is a pair of stars in orbit at a separation so large that their mutual acceleration falls into the range where the modified dynamics departs from Newton's law. The astrophysicist Indranil Banik and his colleagues found Newtonian dynamics preferred over the modified dynamics at 19 standard deviations (Banik and others 2024). Kyu-Hyun Chae has studied wide binaries alone and with colleagues. Chae reported an anomaly of gravity in samples of binaries he selected (Chae 2024), and later, with colleagues, in a sample of 36 wide binaries with accurate velocities in three dimensions (Chae and others 2026). Serat Saad and Yuan-Sen Ting reanalyzed those 36 binaries, modeling their orbits in three dimensions, and found a boost of gravity of 1.00 ($+0.24$, $-0.19$), which is consistent with Newtonian gravity. Saad and Ting recover a boost close to the one Chae and colleagues reported when they replace the semi-major axis of each orbit (half the longest width of the orbit) with a de-projection of the observed separation, an estimate of the true separation of the two stars made from the separation seen on the sky (Saad and Ting 2026). In 2020 Chae, Lelli, Desmond, McGaugh, Li and Schombert reported a detection of the external field effect in rotationally supported galaxies, galaxies whose stars and gas are held up against gravity by rotation (Chae and others 2020). That detection rests on one kind of

measurement. In the study the external field of each galaxy is estimated from the galaxies around it, not measured. The sealed record states no measurement for Prediction 24.

**What decides it.** The sealed record names no measurement that decides Prediction 24. I name the measurement that decides in my relation essay on the modified dynamics, *The Law and the History*: "a sample of galaxies selected and analyzed independently, with the external field separated from the environment of formation, will find the tide and nothing more". In the modified dynamics a wide binary falling in the field of the Milky Way feels the external field effect as a galaxy does, so a Newtonian result for wide binaries bears on the same prediction. A sample of galaxies of that kind would be a second kind of measurement, independent of the wide binaries.

## III. Where the Two Accounts Agree

### Smolin 5. An asymmetry of time in the laws

**The collection predicts.** "No superdeterministic completion of quantum mechanics will be found, and no world is purely and completely deterministic. Some asymmetry of time must exist in the laws, and no process at any scale is perfectly reversible; a reversal of evolution, by an inverse in a formalism or by a pulse in a laboratory, does not remove a finding from the order of findings. These are exclusions that the structure of comparison makes; the outcome of a search for departures from the quantum predictions bears on Prediction 25 and not on this one". I registered this prediction on 1 November 2026 as Prediction 28 of *The Registered Predictions of Physics from Comparison*.

**Smolin predicts.** Smolin holds that time is real and fundamental, and that the laws carry the direction of time. Smolin and the physicist Marina Cortês build models of spacetime from energetic causal sets, in which spacetime emerges from discrete events whose causal links carry energy

and momentum. The principles of the energetic causal sets posit a fundamental irreversibility of time. The dynamics of the sets is asymmetric in time. In the models of Cortês and Smolin a behavior symmetric in time emerges only approximately (Cortês and Smolin 2014). On his principle of precedence, a measurement with no precedent is not fixed by any prior law (Smolin 2012b).

**Where argued.** The Basis of Physics, Essays 9 and 11; Measurement, Chapter 14, Sections II and III; Why Time Travel Is Not a Concept, Chapter 5, Sections III to V.

**Measured.** Two kinds of violation are consistent with the required asymmetry of time, as the sealed record reports: violations of CP, the combined reversal of charge and of left and right (1964), and of time reversal (CPLEAR 1998; BaBar 2012).

**The agreement, exactly.** Both accounts put an asymmetry of time in the laws. On both accounts the future is also open, which means that on each account the present does not fix the future. The energetic causal set models generate new events by a deterministic rule. The collection excludes a perfectly deterministic world, so the exclusion bears on any such rule taken as the whole of physics. That exclusion also agrees with Smolin's principle of precedence, which leaves a measurement without precedent unfixed by any law. The sealed record states plainly that "the outcome of a search for departures from the quantum predictions bears on Prediction 25 and not on this one", so the measurement that decides Smolin 3 does not touch the agreement over an asymmetry of time.

## IV. Predictions Stated Only in the Relation Essay

The relation essay states no prediction of its own, because every prediction that the essay states is argued in the books of the collection and carried in the sealed record, as Predictions 5, 25 and 28.

## V. Where No Measurement Decides

Falsification is the refutation of a claim by a measurement. Falsification applies to a claim about what a measurement will find. The differences set out in this section are of another kind: they are claims about what a law is, about what the passage between epochs is, about the order of the act of knowing, and about the order in which time and space are counted. An epoch is the span of the universe from one turn to the next. The present epoch began at the Big Bang. The turn is the passage from the end of one epoch to the beginning of the next, at the end of every black-hole interior. Every measurement is made within one epoch, under the laws that the measurement would test, by a comparison that already has the structure these claims describe. So no measurement can be set against the claims. Each claim is checked by its argument and by its fit with the rest of the account that makes it.

### Laws that change, and laws that stay the same

The difference over laws is a claim of logical form: a claim about what a law is. Smolin holds that the laws of nature are not immutable. His account lets the laws change so that the future is not contained in the present. He argues the point in a book written with the philosopher Roberto Mangabeira Unger (Unger and Smolin 2014). The collection holds that "A law of physics states what stays the same when the circumstances of a measurement change" (Measurement, Chapter 2, Section V). The collection keeps the future open with laws that stay the same, because determinism "is an assertion of total symmetry and total continuity", and "since symmetry and continuity cannot both be perfected, total specification (continuity) of lawful structure (symmetry) is structurally precluded" (Causality Without Determinism, Chapter 1, Section VIII). On both accounts the future is open, but the two accounts part on what has to change for the future to be open: on Smolin's account the laws change, and on the collection's account the laws stay the same.

### A population of universes, and one next epoch

The difference over the population of universes is a description of what a thing is: a description of the passage at the end of a black-hole interior. Smolin's cosmological natural selection takes each black hole to begin a universe whose constants differ slightly from its parent's, so that universes that make many black holes come to predominate (Smolin 1992; Smolin 1997). The collection shares Smolin's identification of the end of a black-hole interior with the beginning of a universe. The collection reads the identification otherwise: "Every possible comparison therefore gives the end of one interior the same verdicts as the end of another, and the ends are one" (At the Edge of Reality, Chapter 11). So on the collection's account there is one next epoch, and nothing of the old epoch's distinctions crosses the turn as a distinction. The structure of physics is fixed in every epoch by the three axioms. No measurement decides between the two accounts, because no comparison made in this epoch registers the end of an interior, or the epoch that came before this one.

### Precedence held in instances, and precedence held in each act

The difference over precedence is a claim about the act of knowing. Smolin's precedence is a memory of instances: on his principle, nature draws an outcome from the earlier outcomes of the same measurement (Smolin 2012b). The collection's precedence is the order within each single comparison: "The order Axiom II states is one of precedence, not of clock time" (The Last Turtle, Chapter 3, Section VI). On the collection's account the record of each comparison becomes part of the stance (the side from which a comparison is made) from which the next comparison proceeds. Where the principle of precedence predicts a departure that a measurement can find, this record carries the departure as Smolin 3. What remains of the difference concerns where the past is held: in Smolin's account the past is held in the instances of earlier measurements, and in the collection's account the past is held in each act of comparison.

### Time before space, and both counted together

The difference over time and space is a claim of logical form: a claim about the order in which the dimensions are found. In his later work Smolin takes time as fundamental and space as emerging from relations among events. The collection counts time and space from one source. The second axiom orders the three roles of comparison (the immanent, the omniscient and the transcendent) in a cycle with three transitions. The three transitions are identified with the three directions of space. The cycle has one direction, which is identified with the one direction of time (Measurement, Chapter 4, Section VIII). So on the collection's account time is not prior to space, and space does not emerge from time.

### Quantum mechanics incomplete, and complete in its scope

The difference over quantum mechanics is a description of what a thing is: a description of the quantum description itself. Smolin holds that quantum mechanics is incomplete and that a realist completion is still to be found (Smolin 2019). The collection derives the postulates of quantum mechanics from the structure of comparison, and finds that the update of the quantum state upon measurement is "not a physical process" (The Quantum Passage, Chapter 9, Section IV). Smolin 3 sets out the one part of the difference over completeness that a measurement can test. The rest of the difference concerns what the quantum description is, a question that no measurement can test.

## VI. What the Collection Does Not Predict Here

Section IX of the sealed record states what the books of the collection do not predict, so that no later measurement is counted for or against the collection on a question where the collection makes no claim. Five items of that section bear on this record.

> "The value of Newton's constant, the strength of light, the strength of color and the vacuum value of the Higgs field are measured inputs (The Gravitational Passage, Chapter 13; The Strengths of the Kinds, Chapter 1, Section VI; The Measures of the Kinds, Chapter 13, Section X)".
>
> "The dynamics of the transition between epochs, and how the gyrations are made at the turn, are not computed (The Weight of Possibility, Chapter 6)".
>
> "The size of the asymmetry of time is not predicted, only that it exists (The Basis of Physics, Essay 11, Section VII)".
>
> "Below the Planck curvature the account and the effective field theory of gravity give the same result for every experiment now proposed (The Unquantized Arena, Chapter 6, Section IV); a detection of single gravitons, or of a primordial background, would not show gravitation quantized (Chapter 9, Section III; Chapter 18, Section VI)".
>
> "The account asserts neither the return of the information that falls into a black hole formed from a star to the outside world, nor its loss to it (The Unquantized Arena, Chapter 17, Section VII); on the account of The Gravitational Passage that information is not destroyed, and re-emerges in the initial conditions of the next epoch (Chapter 18, Section XIII)".

Two of Smolin's own tests fall outside the collection's predictions. This record states both tests so that neither test is counted for or against the collection. Smolin's cosmological natural selection predicts that "the up-

per mass limit of neutron stars is less than 1.6 solar masses". Smolin names a well-measured neutron star of high enough mass as the observation that would refute the prediction (Smolin 2004, Sections 6.3 and 7). The pulsar PSR J0740+6620, a neutron star, has a mass of 2.08 $\pm$ 0.07 solar masses (Fonseca and others 2021). The collection makes no prediction about the upper mass of neutron stars. Smolin's 2004 statement also names conditions on inflation under which cosmological natural selection would be refuted (Section 6.4). Inflation is a proposed early phase of accelerated expansion of the universe. Smolin's statement does not assert that inflation occurred, so this record sets no entry against Prediction 13, which says that no long inflationary phase occurred.

## VII. The Record at Its Date

| Entry | The collection | Smolin | Measured | Standing |
|---|---|---|---|---|
| Smolin 1. Discrete area and volume | No least length, area or duration; no quantum of the arena (Predictions 5, 3, 29) | Discrete spectra of area and volume | No discrete spectrum observed; no graviton detected | Agrees, for the collection (Predictions 5 and 3); the difference is untested, and no experiment now proposed reaches it |
| Smolin 2. Speed of light | Independent of energy (Prediction 5) | A Planck-scale dependence held open | None above about ten times the Planck energy | Agrees, for the collection; the difference is not yet decided by the rule of decision (one kind of measurement) |

| Entry | The collection | Smolin | Measured | Standing |
|---|---|---|---|---|
| Smolin 3. Quantum statistics | Born weights in every sector (Prediction 25) | Departures for states with few copies or no precedent | Three-slit and network tests agree; no test on states without precedent | Agrees as far as tested, for the collection; the difference is untested, since no test on the first outcomes of states without precedent has been made |
| Smolin 4. Low acceleration | Tide only; no external field effect (Prediction 24) | A regime of quantum gravity reproducing the modified dynamics, with a mass ratio set by the environment | Wide binaries Newtonian at 19 standard deviations; a 2020 detection in galaxies, one kind | Agrees with the wide binaries at 19 standard deviations (one kind); one 2020 report in galaxies against it (one kind); not decided by the rule of decision |
| Smolin 5. Asymmetry of time | Some asymmetry of time in the laws (Prediction 28) | Time fundamental and irreversible | CP and time-reversal violation | Agrees |

## Summary

Lee Smolin's program makes predictions that a measurement can test in four places, and in each place the collection's registered prediction differs from Smolin's. On the speed of light the measurements so far agree with the collection, because they place any dependence of the first order above about ten times the Planck energy. Amelino-Camelia and Smolin pro-

posed a search for high-energy neutrinos, which would add the second kind of measurement that a result needs under the rule of decision. On quantum statistics, every test so far agrees with the Born weights. Smolin himself named the test that would separate the two accounts: a test on states prepared for the first time. On the discreteness of area and volume, the two accounts give the same result for every experiment now proposed, and only a measurement at the Planck scale separates them. On galaxies at low acceleration, the wide binaries agree with the tide. The decision will come from an independent sample of galaxies, with the external field separated from the environment in which the galaxies formed. The two accounts agree that some asymmetry of time is in the laws. Smolin predicts a ceiling on the mass of neutron stars. The ceiling lies outside the collection's predictions, so this record counts the ceiling neither for nor against the collection. The deepest differences between the two accounts are differences of kind, and no measurement can test them: whether laws change, whether universes form a population that inherits its constants, where precedence is held, and whether time comes before space. On both accounts the future is open, but the two accounts part on what has to change for the future to be open.

**Key Concepts**

- The timing of light from distant bursts finds no dependence of the speed of light on its energy, and places any dependence of the first order above about ten times the Planck energy, as Prediction 5 states.
- Every test of the Born weights so far agrees with Prediction 25. The test that separates the two accounts is the one Smolin named: new entangled states, studied as they are first prepared.
- For every experiment now proposed, the discrete spectra of area and volume of loop quantum gravity give the same result as the collection's arena with no least step; only a measurement at the Planck scale separates the two accounts.
- The wide binaries agree with the tide. Prediction 24 is decided by an independent sample of galaxies, with the external field separated from the environment in which the galaxies formed.
- Both accounts put an asymmetry of time in the laws, and both keep the future open.
- No measurement can test the differences of kind: whether laws change, whether universes form a population that inherits its constants, and whether time comes before space.

## Terms

**Arena.** The context of physics, the geometry of space and time within which content is found; on the collection's account, what gravitation is.

**Born rule.** The rule that the probability of a finding is the square of the magnitude of its amplitude.

**Content.** What is found within the arena: the particles, their charges and their fields.

**Cosmological natural selection.** Smolin's proposal that each black hole begins a new universe whose constants differ slightly from its parent's, so that universes that make many black holes predominate.

**Energetic causal set.** A model of Cortês and Smolin in which spacetime emerges from discrete events whose causal links carry energy and momentum.

**Epoch.** The span of the universe from one turn to the next. The present epoch began at the Big Bang.

**Equivalence principle.** The principle that gravitational and inertial mass are equal, so that bodies fall alike and a body falling freely carries its own physics with it.

**External field effect.** In the modified dynamics, the change in a galaxy's internal motions produced by the uniform field of a larger body it falls in; general relativity has no such effect, only the tide.

**Gyration.** The unit of the dark matter on the collection's account: a conserved excitation of the six held internal dimensions, of about the Planck mass.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Loop quantum gravity.** A program that quantizes the geometry of space without a fixed background, in which areas and volumes take discrete values.

**Modified Newtonian dynamics.** Milgrom's law of gravity, which departs from Newton's below a constant of acceleration.

**Planck energy.** The energy fixed by Newton's constant, the speed of light and the reduced Planck constant, about $1.22 \times 10^{19}$ GeV.

**Principle of precedence.** Smolin's proposal that the outcome of a quantum measurement is drawn from the outcomes of earlier instances of the same measurement.

**Real ensemble formulation.** Smolin's proposal that the ensemble a quantum state describes is the set of all systems in that state in the universe.

**Rule of decision.** The rule of the registered predictions: a result counts when it is established at five standard deviations by at least two independent kinds of measurement.

**Spin network.** A graph whose edges and nodes carry labels of spin, used in loop quantum gravity to label the discrete values of area and volume.

**Tide.** The difference in the pull of a distant body across an extended one, which is all of that body's field that a freely falling system feels.

**The turn.** The passage from the end of one epoch of the universe to the beginning of the next, at the end of every black-hole interior; no comparison registers it as an event.

**Wide binary.** A pair of stars in orbit at a separation so large that their mutual acceleration falls into the range where the modified dynamics departs from Newton's.

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The measurements that the sealed record reports by author and year (Abbott and others 2016; Sinha and others 2010; Chen and others 2022; Li and others 2022; CPLEAR 1998; BaBar 2012) are given in full in the bibliographies of the books it names.

Appendix D

# The Registered Predictions Beside Ilya Prigogine

*A Dated Record, 4 November 2026*

Date of record: 4 November 2026. This record is fixed at its date of record, and I do not revise it; a later report will carry its own date. This record sets the predictions of physics from comparison, the account of physics that I set out in the books of the physics collection of the Immanent Metaphysics, beside the predictions of Ilya Prigogine. This record draws on two of my works: on *The Registered Predictions of Physics from Comparison; A Dated Record, 1 November 2026* (DOI https://doi.org/10.67291/RQQS3025), which I do not revise, and on the relation essay *The Arrow Comes First; Ilya Prigogine, Irreversibility and Physics from Comparison*, the essay in which I relate Prigogine's work to physics from comparison.

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## Abstract

Ilya Prigogine and the physics collection of the Immanent Metaphysics agree on what the world will show about time and chance, and this record calls that physics collection the collection, for short. Prigogine and I both hold three things: that the world is not deterministic; that the arrow of time is real, a feature of physics and not a product of our ignorance; and that the pattern a system takes at a branching point far from equilibrium is not fixed in advance. A system is far from equilibrium when a continuing flow of energy and matter keeps it from settling, and a branching point is a point at which such a system can take one of several patterns. I registered the first two of those three claims, that the world is not deterministic and that the arrow of time is real, together as Prediction

28 of the sealed record, the register of predictions that I sealed on 1 November 2026, and the measured violations of time reversal agree with Prediction 28. A violation of time reversal is a measured case in which a process and its reverse in time do not happen at the same rate. I state the third claim, that the pattern taken at a branching point is not fixed in advance, only in the relation essay, and the sealed record does not carry the third claim. In the relation essay I apply the collection's account of amplified hard randomness to Prigogine's dissipative structures, the ordered patterns that a continuing flow of energy and matter maintains far from equilibrium. Hard randomness is an outcome that no prior specification fixes, however complete, and amplified hard randomness is such an outcome magnified into a difference in the behavior of a whole system. The experiments on the crystallization of sodium chlorate agree with the claim that the pattern taken at a branching point is not fixed in advance. Neither the relation essay nor the books name a measurement that separates Prigogine's account from the collection's account. The two accounts part on where irreversibility and chance are found: Prigogine placed both in the dynamics of a class of unstable systems, and the collection places the arrow in the impossibility of faithful reversal and chance at the edge of the domain of measurement, for every world. A faithful reversal is a reversal that retraces exactly the states the original process passed through and arrives at exactly the original condition, and the edge of the domain of measurement is the boundary beyond which no measurement can be made. No experiment can decide the differences between the two accounts on where irreversibility and chance are found, and this record names each difference with the kind of claim it is.

## I. What This Record Is

This record sets two accounts side by side. The first account is physics from comparison, whose predictions I gathered and sealed on 1 November 2026 in the register that this record calls the sealed record. The second account is that of Ilya Prigogine (1917 to 2003), who received the Nobel

Prize in Chemistry in 1977 for the theory of dissipative structures. Prigogine argued, with Isabelle Stengers and with Tomio Petrosky and the Brussels-Austin group, that the arrow of time is real and that probability belongs to the laws of unstable systems.

The collection's account rests on the Incommensuration Theorem: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The Incommensuration Theorem is a structural fact about the nature of knowing. I formulated the first axiom of the Immanent Metaphysics in or before 1991, and I formulated the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996; I did most of my work in physics in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1.

The sealed record states the rule of decision, the rule by which this record judges a measurement against a prediction: "A result counts when it is established at five standard deviations by at least two independent kinds of measurement. A measurement that differs from a prediction by less is a measurement of interest, and the record reports it as such". A standard deviation is the measure of the uncertainty of a measurement. I state each prediction of the collection in this record in one of two ways: quoted from the sealed record with its number, and argued in the books named at chapter and section; or marked as stated only in the relation essay.

## II. Where the Two Accounts Predict Differently

At the date of this record, neither the relation essay nor the books name a measurement on which the two accounts give different results. Prigogine's program changes the physical description of large Poincaré systems, which in his program are dynamical systems with a continuous set of resonances among their motions. The collection keeps the established

description of those systems and reads that description differently. The relation essay sets out where each account places irreversibility and chance, and this record sets out those differences in Section V, because no measurement decides them. So Section II carries no entry.

## III. Where the Two Accounts Agree

### Prigogine 1. The world is not deterministic, and the arrow of time is real

**The collection predicts.** "No superdeterministic completion of quantum mechanics will be found, and no world is purely and completely deterministic. Some asymmetry of time must exist in the laws, and no process at any scale is perfectly reversible; a reversal of evolution, by an inverse in a formalism or by a pulse in a laboratory, does not remove a finding from the order of findings. These are exclusions that the structure of comparison makes; the outcome of a search for departures from the quantum predictions bears on Prediction 25 and not on this one". Registered on 1 November 2026 as Prediction 28 of *The Registered Predictions of Physics from Comparison*. A superdeterministic completion of quantum mechanics is a deterministic theory beneath quantum mechanics in which the settings of an experiment are fixed together with the states of what is measured. Prediction 25 of the sealed record is the prediction that the statistics of quantum theory hold.

**Prigogine predicts.** Determinism fails, and irreversibility is part of the dynamics and not an artifact of approximation or of ignorance. Prigogine states the conclusion in one sentence in *The End of Certainty* (1997), written with Isabelle Stengers: "The more we know about our universe, the more difficult it becomes to believe in determinism". Petrosky and Prigogine (1993) found three things about large Poincaré systems: that the removal of the resonance divergences, the infinite terms that the resonances produce in the calculation, "leads to complex irreducible spectral repres-

entations"; that "irreducibility means that this representation is implementable only by statistical ensembles and not by trajectories"; and that "Complex means that time symmetry is broken". On Prigogine's account, the description of large Poincaré systems has no deterministic completion to be found, and time symmetry is broken in the laws of those systems.

**Where argued.** The Basis of Physics, Essay 9 and Essay 11; Measurement, Chapter 14, Section II and Section III; Why Time Travel Is Not a Concept, Chapter 5, Sections III to V. In the relation essay I also cite the non-polarization principle of Causality Without Determinism, Chapter 1, Section IX: "All worlds are to some non-zero and positive degree causal. No world is purely and completely deterministic".

**Measured.** As the sealed record reports it: "Violations of CP (1964) and of time reversal (CPLEAR 1998; BaBar 2012) are consistent with the required asymmetry". The Basis of Physics, Essay 11, Section VII, reads those violations as "a place where the impossibility of perfecting temporal symmetry has become visible to instruments".

**What decides it.** The sealed record states that the claims of Prediction 28 are exclusions (things ruled out) that the structure of comparison makes, and that a search for departures from the quantum predictions bears on Prediction 25 and not on Prediction 28. Each account says that no deterministic completion will be found, so each further search that finds no deterministic completion agrees with both accounts.

## IV. Predictions Stated Only in the Relation Essay

### Prigogine 2. The pattern taken at a branching point is not fixed in advance

**The collection predicts, in the relation essay.** Where a system far from equilibrium can take one of several patterns, the pattern it takes depends on differences that pass below the microscopic limit when they are followed downward to ever smaller scales, and below that limit the outcome

is hard random; so "no law laid out in advance fixes which branch is taken, and the branch, once taken, is lawful in all that follows" (*The Arrow Comes First*, Section VI). The microscopic limit is the smallest scale at which a measurement can be made.

**Prigogine predicts.** Prigogine named his prediction order through fluctuations: at the point where a system far from equilibrium must take one of several patterns, a fluctuation, a small chance departure from the average state of the system, decides which pattern appears (Prigogine 1977, "Time, Structure and Fluctuations").

**Where argued.** The books of the collection argue the general case, and they do not argue its application to dissipative structures. In The Basis of Physics, Essay 6, Section VI, I follow amplification, the magnifying of small differences into large ones, downward through the three-body problem (the motion of three bodies under their mutual gravitation) and through the weather, to differences that "fall below the limits of measurement, below the microscopic limit", where what produces the outcome is, "from the standpoint of anything inside the domain, hard random". In Measurement, Chapter 12, Section VI, I name the mechanism microstate amplification: the magnification of small differences at a fine-grained level into differences in a system's behavior. In the relation essay I apply the general case of Essay 6 and the mechanism of Chapter 12 to the branching points of dissipative structures.

**Measured.** Kondepudi, Kaufman and Singh (1990) crystallized sodium chlorate, whose crystals are optically active although its molecules are not chiral: from unstirred solution, left-handed and right-handed crystals appeared in roughly equal numbers, and from stirred solution about 99.7 percent of the crystals in a sample shared one handedness. Charles Day (2005), reporting the later experiment of Cristobal Viedma, records that "Left-handed and right-handed crystals have the same chance of forming" and that in Viedma's runs "The dominant form was random".

**What decides it.** The test is a series of runs prepared as alike as instruments allow. On both accounts the pattern taken follows a distribution over the runs, and no preparation fixes the pattern that a single run takes.

**Standing for registration.** I state the prediction of Prigogine 2 in the relation essay. The books argue the general case and not its application to dissipative structures, and the sealed record does not carry the prediction, so this record files the prediction among the predictions outside the sealed record.

## V. Where No Measurement Decides

Falsification is the refuting of a claim by a measurement, and falsification applies to a claim that some outcome of a measurement could contradict. The differences set out in this section are claims of another kind. Each difference is either a claim of logical form, which follows from the structure of comparison itself, or a description of what a thing is, such as a law, a probability or an arrow. Every measurement is itself a comparison made within the structure of comparison, so no outcome of a measurement bears on these differences. I record the differences so that no later measurement is counted for or against either account on a question where neither account makes a claim that a measurement can decide.

### Where the arrow of time lives

Prigogine built irreversibility into the laws. In his extended description of large Poincaré systems, the evolution splits into two semigroups, each an evolution defined in one direction of time only, and Prigogine chooses the semigroup that runs toward equilibrium in the future. The collection finds the arrow of time beneath the laws. In The Basis of Physics, Essay 11, Section III, I write: “Symmetry of the laws guarantees lawful reversal. It does not guarantee faithful reversal”. Lawful reversal is the time reverse of a lawful process being itself lawful, and faithful reversal retraces exactly the states that the original process passed through. Faithful reversal needs a

symmetric law acting on a state specified with no gap, and that conjunction of symmetry with continuity is the conjunction that the Incommensuration Theorem forbids. The direction of time is "the direction in which comparison proceeds" (Incommensuration, Chapter 8, Section X). In Essay 11, Section VII, I add that the laws exhibit time-reversal symmetry "to an extraordinary degree" and that the symmetry "cannot be perfect". The collection's placing of the arrow is a claim of logical form: the claim follows from the Incommensuration Theorem and depends on no entropy, no boundary condition and no formalism.

**Where chance lives**

Prigogine placed probability in the law: on his account the dynamics of a large Poincaré system has an irreducible representation by ensembles, a description that only collections of possible states (ensembles) can carry and that single trajectories cannot carry. The collection places chance at the edge of the domain of comparison, which is the domain of measurement named in the Abstract, where no measurement can be made (The Basis of Physics, Essay 6, Section VII). The collection reads a law of probabilities as structure laid out in advance: "any randomness in it is a distribution laid out in advance; the one outcome that occurs is a finding, and no structure laid out in advance contains it" (Measurement, Chapter 12, Section V). The collection's placing of chance is a description of what a law and a finding are.

**How far the failure of determinism reaches**

Prigogine reached the failure of determinism through instability, so his conclusion applies to systems unstable enough, with resonances dense enough, for the trajectory description (the description of a system by the single paths of its parts) to fail. The collection's route applies to every world, stable or not. Determinism is "the assertion of total symmetry and total continuity, applied simultaneously and without remainder", which is the first conjunction that the Incommensuration Theorem forbids (The

Basis of Physics, Essay 2, Section III), and in that essay I add: "The conclusion does not depend on the results of any experiment". The collection holds that determinism fails in every world, and that claim is a claim of logical form.

### The two arrows and the dispute with the heirs of Boltzmann

Prigogine held that irreversibility is more than statistics. Prigogine's critics held, as Boltzmann had held, that counting states, together with a beginning of the world of low entropy (a highly ordered beginning), explains irreversibility. Jean Bricmont (1996) was among the clearest of those critics. In Measurement, Chapter 12, Section VII, I keep two arrows: the structural arrow "is present in every single comparison" and "needs no large number of parts and no particular beginning of the world"; the entropic arrow "is a statistical arrow" that "needs a beginning of low entropy"; and "each act of recording joins the two arrows in one event". So each side of the dispute is right about one arrow: Prigogine about the structural arrow, which is more than statistics, and his critics about the entropic arrow, which is a statistical arrow. The account of the two arrows is a description of what each arrow is, and the two arrows point the same way wherever both are found, so no measurement separates Prigogine's reading from the reading of his critics.

## VI. What the Collection Does Not Predict Here

One item of Section IX of the sealed record bears on the comparison with Prigogine:

> "The size of the asymmetry of time is not predicted, only that it exists (The Basis of Physics, Essay 11, Section VII)".

The collection requires that some asymmetry of time exist in the laws, but the collection does not say how large the asymmetry is, in which interaction it appears, or through what mechanism it arises. So, whatever size a measurement finds for a violation of time reversal, the measurement counts neither for the collection nor against it. Prigogine's program places the arrow in the dynamics of large Poincaré systems, and it gives no value for the size of a violation of time reversal in any interaction either.

## VII. The Record at Its Date

| Entry | The collection | Prigogine | Measured | Standing |
|---|---|---|---|---|
| Prigogine 1 (Prediction 28) | no world purely deterministic; some asymmetry of time in the laws; no process perfectly reversible | determinism fails; time symmetry broken in the laws of unstable systems | CP violation (1964); time-reversal violation (CPLEAR 1998; BaBar 2012) | agrees as far as tested |
| Prigogine 2 (relation essay only) | the pattern at a branching point is not fixed in advance | order through fluctuations | sodium chlorate: equal chances; one handedness dominates when stirred | agrees as far as tested |

## Summary

Ilya Prigogine argued for half a century that determinism fails, that the arrow of time is real, and that the pattern a system takes far from equilibrium is decided by a fluctuation. The physics collection predicts each of these three things. I registered the first two together as Prediction 28 of the sealed record, and the measured violations of CP and of time reversal agree with Prediction 28; a violation of CP is a difference between a pro-

cess and its mirror image with particles exchanged for antiparticles. The third claim is that the pattern a system takes far from equilibrium is decided by a fluctuation. I state the third claim in the relation essay, where I apply the collection's account of amplified hard randomness to dissipative structures; the crystallization of sodium chlorate agrees with the third claim, and the sealed record does not carry the third claim. Neither the relation essay nor the books name a measurement that separates the two accounts. The two accounts part on where the arrow and chance are found, and on how far the failure of determinism reaches: Prigogine found the arrow and chance in the dynamics of a class of unstable systems, and the collection finds the arrow in the impossibility of faithful reversal and chance at the edge of the domain of measurement, for every world. Those differences are claims of logical form and descriptions of what a law and an arrow are, and no outcome of a measurement bears on them. The size of the asymmetry of time is predicted by neither account.

**Key Concepts**

- Prigogine shares Prediction 28 of the sealed record, that no world is purely deterministic and no process perfectly reversible.
- Lawful reversal and faithful reversal: symmetric laws guarantee lawful reversal and never guarantee faithful reversal.
- Prigogine placed the arrow and chance in the dynamics of large Poincaré systems; the collection places the arrow in comparison and chance at the edge of the domain of measurement.
- The pattern taken at a branching point is not fixed in advance; this prediction is stated in the relation essay, outside the sealed record.
- The size of the asymmetry of time is not predicted, only that it exists.

## Terms

**CP violation.** A difference between a process and its mirror image with particles exchanged for antiparticles; by the CPT theorem it entails a violation of time reversal.

**Chiral symmetry breaking.** The appearance, from conditions that favor neither, of a population dominated by one handedness.

**Dissipative structure.** An ordered pattern maintained by a continuing flow of energy and matter far from equilibrium.

**Entropic arrow.** The statistical arrow of time, found in systems of very many parts and needing a beginning of low entropy.

**Faithful reversal.** A reversal that retraces exactly the states the original process passed through and arrives at exactly the original condition.

**Hard randomness.** An outcome that no prior specification fixes, however complete; no capacity for causal prediction exists for it.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Large Poincaré system.** In Prigogine's program, a dynamical system with a continuous set of resonances among its motions.

**Lawful reversal.** The time reverse of a lawful process being itself lawful.

**Microstate amplification.** The magnification of small differences at a fine-grained level into differences in a system's behavior.

**Non-polarization principle.** Every world is to some degree causal, and no world is purely deterministic.

**Order through fluctuations.** Prigogine's name for the selection, by a fluctuation, of one pattern among several at a branching point far from equilibrium.

**Rule of decision.** The rule of the registered predictions: a result counts when it is established at five standard deviations by at least two independent kinds of measurement.

**Semigroup.** In Prigogine's program, an evolution defined in one direction of time only; the extended description splits into two, and the one running toward equilibrium in the future is chosen.

**Standard deviation.** The measure of the uncertainty of a measurement; a difference of five standard deviations is the usual threshold for a discovery in physics.

**Structural arrow of time.** The direction in which comparison proceeds: from the range of what is possible, through the act, to the record.

**Superdeterminism.** A deterministic completion of quantum mechanics in which the settings of an experiment are fixed together with the states of what is measured, so that statistical independence fails; it is proposed, and the choices of measurement are correlated in advance with what is measured.

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Appendix E

# The Registered Predictions Beside Robert Rosen

*A Dated Record, 4 November 2026*

Date of record: 4 November 2026. This record is fixed at that date and is not revised; a later report will carry a date of its own. This record sets the predictions of physics from comparison, the physics of the Immanent Metaphysics, beside the predictions of the biologist Robert Rosen. This record draws on two works: on *The Registered Predictions of Physics from Comparison; A Dated Record, 1 November 2026* (DOI https://doi.org/10.67291/RQQS3025), which remains as it was sealed, and on the relation essay *No Largest Model; Robert Rosen, Relational Biology and Physics from Comparison*, which is the essay that sets Rosen's account beside physics from comparison.
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## Abstract

Robert Rosen and the physics collection of the Immanent Metaphysics share three conclusions: relation comes before the things related; a model, however well it fits, is not the thing it models; and a living being is not a mechanism. The physics collection is the set of books in which I set out the physics of the Immanent Metaphysics. Almost every conclusion that the two accounts share, and almost every point that they dispute, is a claim on which no measurement bears. Rosen's claims concern organisms and the models of organisms, while the sealed record of 1 November 2026, the register of forty-two predictions of physics from comparison, holds predictions of physics. Rosen's claims and the predictions of the sealed record bear on one another in three places. First, the two accounts

> agree that an anticipatory system (a system that changes its present state according to what a model it holds predicts for a later instant) acts on a model it holds in the present, and needs no signal from a later time. The sealed record registers that claim, for every process, as Prediction 27. Second, the collection claims that no natural system has a largest model (a model of the system from which every other model of it follows), and only one prediction puts that claim to a measurement, Prediction 29: for any one fixed discrete rule offered as the foundation of physics, a sensitive enough measurement tells the rule's statistics from the world's. Rosen's account neither states Prediction 29 nor denies it. Third, every model leaves a remainder, the part of what the model renders that the model approaches as closely as one wishes and does not contain. The collection grounds that remainder in hard randomness, an outcome that no prior specification fixes, and hard randomness carries the exclusion of Prediction 28, that no world is purely deterministic. Rosen argues that an organism cannot be simulated, and his argument runs through the self-reference of closure and not through chance. Closure here is closure to efficient causation, Rosen's defining property of an organism: every process that makes some part of the organism is itself made within the organism. The sealed record carries no prediction on which the two accounts give different results, and the relation essay states none. The remaining differences between the two accounts are claims of logical form, descriptions of what a thing is, or claims about the act of knowing, and this record names the kind of each difference. The remaining differences concern five questions: where the line between mechanism and organism falls; whether a proof about a diagram settles a question about an organism; where the remainder of a model comes from; where the line between the living and the non-living falls; and where closure is found.

## I. What This Record Is

This record sets two accounts side by side. The first account is physics from comparison, whose predictions were gathered and sealed in one register on 1 November 2026. The second account is that of the biologist

Robert Rosen (1934 to 1998). Rosen trained under the biologist Nicolas Rashevsky in relational biology, the program of research whose starting point is that what makes a thing alive is how its parts are organized, and not the stuff it is made of. In 1958 Rosen gave relational biology its first exact form in the metabolism-repair systems, abstract diagrams of components that make one another, and he carried the program through *Anticipatory Systems* (1985), *Life Itself* (1991) and the posthumous *Essays on Life Itself* (2000). Rosen saw that a living system is a closed web of relations and not a list of parts, and he saw it earlier than most workers in the life sciences. He also gave that web of relations an exact mathematical description.

The account of the collection rests on the Incommensuration Theorem: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The Incommensuration Theorem is a structural fact about the nature of knowing. I formulated the first axiom of the Immanent Metaphysics in or before 1991, and the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996; I did most of my physics work in 1997 and 1998. My book *An Immanent Metaphysics*, published in 2001, states the Incommensuration Theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1.

This record uses the rule of decision of the sealed record, which is the rule that says when a measurement counts: "A result counts when it is established at five standard deviations by at least two independent kinds of measurement. A measurement that differs from a prediction by less is a measurement of interest, and the record reports it as such". This record quotes every prediction of the collection from the sealed record, with its number, and each prediction is argued in the books named, at the chapter and section given. Where either account makes a claim that is not a prediction of a measurement, this record says what kind of claim it is. The reason is that no later measurement or simulation should be counted for or against either account on a point where neither account makes a claim that a measurement can test.

## II. Where the Two Accounts Predict Differently

At this date the sealed record carries no prediction on which the two accounts give different results, and the relation essay names none. Rosen makes two claims about organisms that bear on observation: that living things act on predictive models they hold of themselves and of their surroundings, and that the organization of a living thing is closed to efficient causation. The collection agrees with the first claim (Section III). The collection reads the second claim as a description of organization, and it places that organization in the transcendent role, the role of the stance and the range of possibility from which an act proceeds (Section V). Rosen's central claim of difference is that an organism has a model that no machine can simulate, and that claim is a claim of mathematics about the models of a system. The relation essay treats the debate over Rosen's proof of that claim as a question settled by proof (Section V). Section II therefore carries no entry.

## III. Where the Two Accounts Agree

### Rosen 1. Anticipation needs no signal from a later time

**The collection predicts.** "A finding changes no geometry, here or anywhere, and news of a distant finding enters a record only at an event on or within the future light cone of the finding. Until such a signal arrives, every local statistic follows quantum theory unchanged, whatever measurement was chosen far away. No signal crosses the boundary of comparison, and no body arrives somewhere that is not in its cone. The probabilities of a preparation's outcomes do not depend on which test is chosen later, and no later finding comes to precede an earlier one. Travel within the cone is not excluded, nor the recession of distant galaxies faster than light, which is a growth of the arena between them and not a signal across it". The prediction was registered on 1 November 2026 as Prediction 27 of *The Registered Predictions of Physics from Comparison*.

**Rosen predicts.** In Rosen's definition, an anticipatory system is "a system containing a predictive model of itself and/or its environment, which allows it to change state at an instant in accord with the model's predictions pertaining to a later instant" (Rosen 1985). The prediction that guides the change of state is a state of the model, and the model is part of the system at the instant the system acts. Rosen held that anticipation of this kind is everywhere in living things, and on Rosen's account anticipation runs on no signal from a later instant.

**Where argued.** The Unquantized Arena, Chapter 7, Section IV (Proposition 7.2); The Basis of Physics, Essay 10; Measurement, Chapter 14, Section IV; The Quantum Passage, Chapter 8, Section III, and Chapter 11, Section III; Why Time Travel Is Not a Concept, Chapter 4, Section IV (Proposition 4.6). The relation essay applies Prediction 27 to anticipation through the cycle of the second axiom of the Immanent Metaphysics, which I set out in Measurement, Chapter 4, Section VIII: "The second axiom orders the three roles in a cycle with three transitions: from the stance to the act, from the act to the laid-out finding, and from the laid-out finding to a new stance". An anticipatory system is a system in which the last of those three transitions, from the laid-out finding to a new stance, is carried by a model the system holds of itself. The relation essay states the same point: "No cause runs backward from the future: the model is present, and it acts by shaping the range of the present act" (*No Largest Model*, Section VII).

**Measured.** The sealed record reports no measurement under this prediction.

**What decides it.** Each account predicts that no anticipatory system needs a signal from a later time, so no measurement separates the two accounts. Prediction 27 says that no record will be found, in any system, in which a later finding comes to precede an earlier one.

## IV. Predictions Stated Only in the Relation Essay

The relation essay states no prediction of measurement beyond those that the books of the collection argue. The relation essay makes claims about Rosen's account, and each of those claims is of a kind recorded in Section V and is argued in the books that the essay cites.

## V. Where No Measurement Decides

Falsification is the refuting of a claim by the outcome of a measurement, and it applies to a claim that some outcome of a measurement could contradict. The differences in this section are of three other kinds: claims of logical form, which follow from the structure of comparison itself; descriptions of what a thing is, such as a model, a mechanism or a living being; and claims about the act of knowing, such as what a description from outside can contain. Every measurement is a comparison made within the structure of comparison, and every measurement is a description from outside, so no outcome of a measurement bears on claims of these three kinds. This record sets out the differences so that no later measurement or simulation is counted for or against either account on a point where neither account makes a claim that a measurement can test. Three sealed predictions of the collection bear on the ground of these differences, and each prediction is quoted in full at the place where it bears.

### Whether any natural system has a largest model

Rosen called a natural system a mechanism when every model of the system can be simulated, so that the models of the system have a largest model, from which every other model follows. Rosen called a system complex when the system has a model that cannot be simulated, and he held that an organism is complex (Rosen 1991). Rosen held complexity to be the general case, and the simple systems of physics to be the special case. Rosen developed complexity "as a description of this more generic view

promoted by biology", in the words of Donald Mikulecky's review of Rosen's *Essays on Life Itself*. The collection finds that no natural system, organism or stone, has a largest model. A model works by symmetry, as I state in Causality Without Determinism, Chapter 5, Section II: "Any form of modeling inherently depends on symmetry". The definition of the classical in that section includes a purpose: "If a model of a thing can be built that behaves identically to the original for all purposes one cares about, then that thing is classical". A model that served every purpose would leave no gap anywhere between itself and the original, and a rendering with no gap is continuity perfected (a model is one kind of rendering). A model that served every purpose at once would be symmetry perfected and continuity perfected together, and that pair is the first pair that the Incommensuration Theorem forbids. So every rendering "leaves a remainder", and the remainder is "the part of what is rendered that a rendering approaches as closely as one wishes and does not contain" (Physics Is Not Math, Chapter 21, Section V). I state the same point in The Ground of Objection, T2.18: "A description is a comparison; therefore no description of any actual thing is complete, and this is a theorem the system derives and builds on rather than a limitation it concedes". On the collection's reading, Rosen's mechanism is a property of a description: a system described for a purpose for which what the description leaves out makes no difference. The claim that no natural system has a largest model is a claim of logical form, and a description of what a model and a mechanism are.

One prediction, and only one, puts the claim that no natural system has a largest model to a measurement, and that prediction concerns the foundation of physics:

> "For any one fixed discrete rule offered as the foundation of physics, a sensitive enough measurement, reaching below the rule's least step, tells the rule's statistics from the world's. The established findings of physics are reproduced at the foundation only by a theory of the conjugate kind".

A theory of the conjugate kind is a theory whose formalism and findings are in conjugate modes, so that "the formalism is governed by the conjugate of the character that governs the findings" (*The Unquantized Arena*, Chapter 2). A cellular automaton, which is a discrete rule, carries one character in its formalism and in its findings, and so a cellular automaton is not a theory of the conjugate kind. The prediction was registered on 1 November 2026 as Prediction 29 of *The Registered Predictions of Physics from Comparison*, and it is argued in The Unquantized Arena, Chapter 3, Section II and Section VI, The Basis of Physics, Essay 18, Section VII, and Measurement, Chapter 8, Section VIII. The sealed record reports no measurement under it. I state both sides of what a model can do in Causality Without Determinism, Chapter 5, Section VIII, the section that the relation essay cites on simulation: "A deterministic simulation can reproduce the statistics of quantum outcomes to any precision chosen in advance", and "For any one fixed program, beyond its smallest step, a sensitive enough measurement eventually tells the program's statistics from the world's". Prediction 29 concerns a discrete rule offered as the foundation of physics. Rosen's account neither states Prediction 29 nor denies it, because Rosen's mechanism concerns which models of a system can be simulated, and not what rule lies beneath physics. Where a simulation of an organism matches the organism's data to a precision chosen in advance, the match

is counted against neither account: the collection states that such a match can be made, and Rosen's claim concerns the existence of a model that no machine simulates, not the precision of any one simulation.

### Whether a proof about a diagram settles a question about an organism

Closure to efficient causation is Rosen's defining property of an organism: every process that makes some part of the system is itself made within the system. Rosen's claim that closure to efficient causation forbids simulable models rests on a proof in the mathematics of categories (category theory, a branch of mathematics that describes structures by the maps between them), and the proof has been disputed. Chu and Ho (2006) argued that some of the central notions of Rosen's proof are not well defined, and that the proof does not hold. Louie (2007), Rosen's student, replied that a living system must have models that cannot be computed, and Chu and Ho (2007) answered him. Mossio, Longo and Stewart (2009) gave an expression of closure to efficient causation in the lambda calculus, a formalism of computation, and argued that closure does not by itself rule out computable models. The relation essay says what kind of question the debate is: "Whether closure to efficient causation, written as a formal property of a diagram, forces a non-computable model is a question of mathematics, settled by proof. Whether a living being is a mechanism is a question about the world, and the formal property is a rendering of it" (*No Largest Model*, Section IV). The order of depth runs metaphysics, then physics, then computation, then mathematics, and each later member renders the earlier (Physics Is Not Math, Chapter 5). By the order of depth, a rendering cannot set the scope of what it renders, and so the formal property of a diagram cannot set the scope of the question whether a living being is a mechanism. The collection concludes on two grounds of its own that a living being is not a mechanism, and neither ground uses any step of Rosen's categorical proof. The first ground is the remainder that every model leaves. The second ground is the bound triple, the arrow of time, hard

randomness and the subjective taken as one, which a computation lacks. I write in Causality Without Determinism, Chapter 5, Section VI that "classical computation, however intricately organized, cannot be what consciousness is". The collection's conclusion is a claim of logical form, and the debate over Rosen's proof is a question of mathematics; no measurement settles either one.

**Where the remainder comes from**

The collection grounds the remainder in hard randomness, an outcome that no prior specification fixes, however complete. Every interaction is a comparison, by the Root Tautology (comparison, interaction and relation are one act under three names), and every comparison leaves an outcome that nothing prior fixes (Causality Without Determinism, Chapter 5, Section IV). Hard randomness carries an exclusion that the sealed record registers:

> "No superdeterministic completion of quantum mechanics will be found, and no world is purely and completely deterministic. Some asymmetry of time must exist in the laws, and no process at any scale is perfectly reversible; a reversal of evolution, by an inverse in a formalism or by a pulse in a laboratory, does not remove a finding from the order of findings. These are exclusions that the structure of comparison makes; the outcome of a search for departures from the quantum predictions bears on Prediction 25 and not on this one".

The prediction was registered on 1 November 2026 as Prediction 28 of *The Registered Predictions of Physics from Comparison*, and it is argued in The Basis of Physics, Essay 9 and Essay 11, Measurement, Chapter 14, Section II and Section III, and Why Time Travel Is Not a Concept, Chapter 5, Sections III to V. The sealed record reports: "Violations of CP (1964) and of time reversal (CPLEAR 1998; BaBar 2012) are consistent with the required asymmetry". A violation of CP is a difference between a process and its

mirror image with particles exchanged for antiparticles, and CPLEAR and BaBar are the experiments that reported the violations of time reversal. Rosen's argument that an organism cannot be simulated rests on a different ground. Closure to efficient causation folds the system back on itself, so that a description of the system must refer to itself, and Rosen argued that this self-reference cannot be captured in any model a machine can simulate. Rosen's argument rests on self-reference and not on chance, so the measurements reported under Prediction 28 agree with the collection and do not bear on Rosen's argument. The two grounds are hard randomness and self-reference, and the difference between them is a claim of logical form.

**Where the line between the living and the non-living falls**

Rosen drew the line between organism and mechanism by a property of organization that is visible in a relational diagram (a diagram of the relations among the parts of a system): closure to efficient causation. The collection agrees that a living being is different in kind from a stone, and it places the difference in something that no diagram can show. I set the difference out in Home in the World, "A Village That Is Alive": "The difference in kind lies elsewhere: in whether choice is gathered, held together and carried forward as one's own, and known from inside. A self is that gathering". The same passage of *Home in the World* says why no measurement can draw the line between the living and the non-living: "a true choice, seen from outside, looks exactly like chance, so no description from outside can draw the line". The Immanent Metaphysics names three roles of comparison, the modalities: the immanent, which is held in the act; the omniscient, which is held as structure laid out; and the transcendent, which is the stance and the range of possibility. The collection places Rosen's closure in the transcendent role, as the organization from which a living being's activity proceeds, and it places the autopoiesis of Humberto Maturana and Francisco Varela in the same role. Autopoiesis is a network of processes of production that continuously regenerates the network that

produced it. The organism living in its surroundings is in the immanent role, and Rosen's diagram of the organization is a model laid out as structure, which is the omniscient role. I state the relation between the omniscient role and the transcendent role in The Last Turtle, Chapter 3, Section XIII: "the omniscient cannot contain the transcendent". So Rosen's diagram, which is in the omniscient role, cannot contain the organization it renders, which is in the transcendent role. Rosen drew the line of life by organization, and the enactivists draw it the same way; Evan Thompson, one of the enactivists, builds his enactive account on autopoiesis. The collection finds the relating, and some degree of choice, on both sides of that line. I state the collection's side in The Ground of Objection, T4.6: "There is no non-conscious interaction, and every interaction has a subjective aspect". I name the collection's side as the one place where the collection parts from the enactive account, in The Immanent Metaphysics and the Modern Engagement, Chapter 9: "the question of whether the modalities extend to non-living systems, which Thompson's framework does not affirm and the Immanent Metaphysics requires". The collection's placing of the line is a description of what a living being is, and a claim about the act of knowing: the claim says that a description from outside, which every measurement is, cannot draw the line between the living and the non-living.

**Where closure is found**

Rosen found closure to efficient causation in the living cell, and he took impredicative loops of this kind to mark the living off from the mechanical. A loop is impredicative when its description defines a thing in terms of a whole to which the thing belongs. The collection finds closure of the same form as Rosen's loops at its own foundation, in every act. The Root Tautology is a loop: every interaction is a comparison, every comparison a relation, and every relation an interaction, and none is first. I describe the closure of the foundation in The Last Turtle, Chapter 3, Section IX: "the axioms describing themselves is itself a process, an instance of the general

class of process, and Axiom II is the axiom of process. So the axioms describe not only themselves but the process of describing themselves. That is full closure over the reification of the foundation". I say what kind of closure the foundation claims in The Ground of Objection, T2.18: "The closure claimed is a closure of the descriptive apparatus and not of the inquiry". On the collection's account, in a living being the closure present in every act of comparison is taken up by one self, which keeps making itself from what it has done. Every comparison passes from a recorded finding to a new stance, and in a self that passage is carried by a model the self holds of itself; a passage carried in that way is anticipation. The collection's finding of closure in every act is a claim of logical form.

## VI. What the Collection Does Not Predict Here

No item of Section IX of the sealed record bears on this comparison of the two accounts. Section IX of the sealed record names the quantities of physics that I take from measurement, or leave open, in physics from comparison: the constants that enter as measured inputs, the Hubble constant apart from the matter fraction, the amplitude and tilt of the primordial departures, the dynamics of the transition between epochs, the size of the excess of matter over antimatter, the values of the kinds, the size of the asymmetry of time, the agreement with the effective field theory of gravity below the Planck curvature, the fate of information that falls into a black hole, and the feasibility of travel within the light cone. Rosen's account makes no claim about any of those quantities.

## VII. The Record at Its Date

| Entry | The collection | Rosen | Measured | Standing |
|---|---|---|---|---|
| Rosen 1 (Prediction 27) | no signal faster than light and none backward in time; no later finding comes to precede an earlier one | an anticipatory system acts on a predictive model it holds at the instant it acts | no measurement reported in the sealed record | untested in the sealed record; the two accounts agree |

Predictions 28 and 29, quoted in Section V, bear on the ground of the collection's differences with Rosen and not on a measurement that separates the two accounts. The sealed record reports measurements consistent with Prediction 28 and none under Prediction 29.

## Summary

Robert Rosen and the physics collection agree that relation comes before the things related, that a model is not the thing it models, and that a living being is not a mechanism. Rosen and the collection agree as well that anticipation, which Rosen found everywhere in the living, needs no signal from a later time. The model that guides an anticipatory system is present in the system, and Prediction 27 of the sealed record says that no later finding comes to precede an earlier one, in any system. No prediction of the sealed record, and none in the relation essay, separates the two accounts by measurement. The differences between the two accounts are of kinds other than predictions of measurement. The collection finds that no natural system has a largest model, and reads Rosen's mechanism as a property of a description. Only one prediction puts the claim that no natural system has a largest model to a measurement: Prediction 29, which concerns a discrete rule offered as the foundation of physics, and which Rosen's account neither states nor denies. The debate over Rosen's categorical proof is a question of mathematics, and the collection's conclu-

sion uses no step of that proof. The collection grounds the remainder in hard randomness, which carries Prediction 28, while Rosen grounds the claim that an organism cannot be simulated in the self-reference of closure. Rosen drew the line of life by organization. The collection draws the line at choice gathered into a self and known from inside, a line that no description from outside can draw, and the collection finds closure at the foundation of every act. The differences named in this summary are claims of logical form, descriptions of what a thing is, and claims about the act of knowing, and no outcome of a measurement bears on any of them.

**Key Concepts**

- Neither the sealed record nor the relation essay states a measurement that separates Rosen's account from the collection's; the differences between the two accounts are of kinds that no outcome of a measurement can falsify.
- Rosen's anticipation runs on a model present in the system, and Prediction 27 says that no later finding comes to precede an earlier one. Rosen's account and the collection agree.
- No natural system has a largest model, because every rendering leaves a remainder; Rosen's mechanism is a property of a description.
- Prediction 29: for any one fixed discrete rule offered as the foundation of physics, a sensitive enough measurement tells the rule's statistics from the world's.
- A simulation that matches its data to a precision chosen in advance counts against neither account.
- The debate over Rosen's proof is a question of mathematics; the collection's conclusion uses no step of that proof.
- In the collection, the remainder comes from hard randomness, which carries Prediction 28; in Rosen's account, an organism cannot be simulated because of the self-reference of closure.
- The difference in kind between the living and a stone is choice gathered into a self and known from inside, which no description from outside can draw.

## Terms

**Anticipatory system.** In Rosen's usage, a system containing a predictive model of itself or its surroundings, which changes its present state according to what the model predicts for a later instant.

**Autopoiesis.** Maturana and Varela's term for a network of processes of production that continuously regenerates the network that produced it.

**Bound triple.** The arrow of time, hard randomness and the subjective, distinct, inseparable and not interchangeable; consciousness is the bound triple taken as one act.

**Closure to efficient causation.** Rosen's defining property of an organism: every process that makes some part of the system is itself made within the system.

**Complex system.** In Rosen's usage, a natural system with at least one model that cannot be simulated.

**Conjugate kind.** A theory whose formalism and findings are in conjugate modes, so that "the formalism is governed by the conjugate of the character that governs the findings" (*The Unquantized Arena*, Chapter 2); a cellular automaton, whose formalism and findings carry one character, is not of this kind.

**CP violation.** A difference between a process and its mirror image with particles exchanged for antiparticles; by the CPT theorem it entails a violation of time reversal.

**Discrete rule.** A rule acting on states that change in least steps, the same at every place and every step, such as a cellular automaton.

**Hard randomness.** An outcome that no prior specification fixes, however complete; the remainder every comparison leaves.

**Impredicative.** Defined in terms of a whole to which the thing defined belongs.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Largest model.** In Rosen's usage, a model of a system from which every other model of it follows.

**Light cone.** The set of events that a signal at the speed of light, or slower, can reach from a given event (its future light cone) or could have come from (its past light cone).

**Mechanism.** In Rosen's usage, a natural system all of whose models can be simulated, so that they have a largest model.

**Modalities.** The three roles of comparison: the immanent (held in the act), the omniscient (held as structure laid out), the transcendent (the stance and the range of possibility).

**Modeling relation.** Rosen's account of a model: states of a natural system encoded into a formal system, inference run, and the result decoded into a prediction.

**Order of depth.** Metaphysics, then physics, then computation, then mathematics; each later member renders the earlier and cannot set its scope.

**Remainder.** The part of what is rendered that a rendering approaches as closely as one wishes and does not contain.

**Root Tautology.** Comparison, interaction and relation are one act under three names.

**Rule of decision.** The rule of the registered predictions: a result counts when it is established at five standard deviations by at least two independent kinds of measurement.

**Simulation.** A computation by a machine that follows a fixed procedure, offered as a model of a system.

**Standard deviation.** The measure of the uncertainty of a measurement; a difference of five standard deviations is the usual threshold for a discovery in physics.

**Superdeterminism.** A deterministic completion of quantum mechanics in which the settings of an experiment are fixed together with the states of what is measured, so that statistical independence fails; it is proposed, and the choices of measurement are correlated in advance with what is measured.

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Appendix F

# The Registered Predictions Beside Giulio Tononi

*A Dated Record, 4 November 2026*

Date of record: 4 November 2026. This record is fixed at its date of 4 November 2026 and is not revised, and a later report will carry a date of its own. This record sets the predictions of physics from comparison, the physics of the Immanent Metaphysics, beside the predictions of the neuroscientist Giulio Tononi. This record draws on two sources. The first source is *The Registered Predictions of Physics from Comparison; A Dated Record, 1 November 2026* (DOI https://doi.org/10.67291/RQQS3025), which is not revised; I call that dated record the sealed record. The second source is the relation essay *The Measure of an Inside; Giulio Tononi's Integrated Information and Physics from Comparison*, the chapter of this volume that sets Tononi's account beside physics from comparison.

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## Abstract

Giulio Tononi's Integrated Information Theory has done what a theory of consciousness seldom does: its proponents have stated in advance where in the brain, and in what pattern of activity, conscious perception will be found, and they have put those statements to a preregistered test against a rival theory, a test whose predictions were fixed in public before any participant was measured. In this record, the collection is the set of books in which I set out physics from comparison. The collection makes no statement about which regions of the brain, or which patterns of their activity, go with conscious perception, and the sealed record of 1 November 2026 holds predictions of physics only. So no measurement made or

> proposed separates the two accounts, and this record says so plainly. One statement of the books bears on the brain and can be measured: the statement that the brain operates near criticality, the poise between order and disorder in which small disturbances cascade. The books argue that the brain's poise near criticality is the physical circumstance under which consciousness is expressed in us, the sealed record does not carry that statement, and the measurements made so far agree with the statement. Tononi's account places consciousness in integrated information, and not in criticality as such; integrated information is the measure of how far a system's power to cause and to be caused upon itself cannot be reduced to the power of its parts. Where Tononi's account and the collection part, the claims are of a kind that no experiment reaches, which means that no experiment can test a claim of that kind. The two accounts part on four questions: what experience is, whether a wholly determined system can have experience, what fixes the quality of an experience, and what the grades of experience are grades of. This record names each of the four differences and the kind of claim that each difference is. On claims of the same kind, which no experiment reaches, the two accounts also agree: a network that only passes signals forward has no consciousness, a program as such has no consciousness, and no test of behavior can show an inside, an experience had from within.

## I. What This Record Is

This record sets the predictions of physics from comparison beside the predictions of Integrated Information Theory, the theory of consciousness that Tononi proposed in 2004 and that he and his colleagues stated in its current form, Integrated Information Theory 4.0, in 2023. This record takes the collection's predictions from the sealed record and from the books that this record cites, and it takes Tononi's predictions from his own published work and from the tests made of that work.

The sealed record fixes what counts as a result: “A result counts when it is established at five standard deviations by at least two independent kinds of measurement”. The sealed record goes on: “A measurement that differs from a prediction by less is a measurement of interest, and the record reports it as such”. The sealed record states that rule of decision for the measurements of physics, and this record reports the measurements of the brain named below as measurements of interest.

Every prediction of the collection that this record states is either quoted from the sealed record with its number, or argued in a book that this record names at chapter and section, or marked as stated only in the relation essay. Nothing in this record alters the sealed record, and this record adds no prediction to the sealed record.

## II. Where the Two Accounts Predict Differently

No entry. The predictions of Integrated Information Theory (IIT) that have been tested concern the brain. In 2016 the neuroscientists Christof Koch, Marcello Massimini, Melanie Boly and Tononi wrote that the correlates of consciousness, the brain activity that goes with conscious experience, are “primarily localized to a posterior cortical hot zone that includes sensory areas”, “rather than to a fronto-parietal network involved in task monitoring and reporting”. The posterior hot zone is a region at the back of the cortex, the outer layer of the brain; the hot zone includes the sensory areas. An adversarial collaboration is a test in which the proponents of rival theories agree beforehand on the experiment, on each theory’s predictions and on how the results will be read. In the adversarial collaboration published in *Nature* on 30 April 2025, two groups of proponents worked with a consortium of researchers neutral between them: the proponents of Integrated Information Theory and the proponents of its rival, global neuronal workspace theory. Before 256 participants were measured by three methods, the proponents and the consortium preregistered “divergent predictions, expected outcomes and interpretation thereof”. The

consortium found information about conscious content in visual, ventrotemporal and inferior frontal cortex, and reported: "For IIT, a lack of sustained synchronization within the posterior cortex contradicts the claim that network connectivity specifies consciousness". In global neuronal workspace theory, ignition is a sudden, widespread rise of activity across the brain when a content becomes conscious. The consortium's results challenged global neuronal workspace theory in its turn, by "the general lack of ignition at stimulus offset and limited representation of certain conscious dimensions in the prefrontal cortex".

Tononi deserves full credit for the test of 2025. When the proponents of a theory state beforehand what will be found, and accept a result that goes against one of their predictions, they have done exactly what this record is for. The collection makes no statement about which regions of the brain, or which patterns of their activity, go with conscious perception, so the results of the test count neither for nor against the collection. The collection's own words on neuroscience are plain: "Neuroscience studies the omniscient-modal aspect of consciousness, and that work is genuine, valuable, and necessary" (*The Immanent Metaphysics and the Modern Engagement*, Chapter 7, Section XV). In the collection's terms, the omniscient-modal aspect of consciousness is consciousness as it is held in structure laid out, with every case in view at once. Integrated Information Theory makes no prediction about gravitation, cosmology or the kinds of particle, and those subjects are what the predictions of the sealed record concern; so no prediction of the sealed record is one on which the two accounts differ.

## III. Where the Two Accounts Agree

No entry. The two accounts share no prediction that a measurement can decide. The agreements of the two accounts are claims of the kind that no experiment reaches, and this record sets the agreements out in Section V, with the differences of that kind, under the heading "Where the two agree, on claims of the same kind".

## IV. Predictions Not in the Sealed Record

Two statements bear on Tononi's account and are not in the sealed record: one statement that the books argue and that no record has registered, and one statement that I make in the relation essay.

### Tononi 1. The brain operates near criticality

**The collection predicts.** A neuronal avalanche is a cascade of activity in a network of nerve cells. In *The Basis of Physics*, Essay 19, Section V, I mark the claim that the brain operates near criticality as the stronger of two claims: "The brain, on this account, operates near criticality, as the study of neuronal avalanches suggests (Beggs and Plenz, 2003), in a regime where small perturbations cascade, so that indeterminacy at the microscopic scale enters causal chains that reach the macroscopic and bear on choice". In the collection, the bound triple is the arrow of time, hard randomness and the subjective, which are distinct, inseparable and not interchangeable, and which, taken as one act, are consciousness. In *Causality Without Determinism*, Chapter 5, Section IX, I say what the claim about criticality is and what that claim is not: "The brain's poise between order and disorder, which physicists call criticality, is the physical circumstance under which the bound triple is expressed in us; it is not the bound triple itself". The books argue that the brain's poise near criticality is the physical

circumstance under which the bound triple is expressed in us, and they state that claim at the strength of its evidence; the sealed record does not carry the claim.

**Tononi predicts.** Tononi's account ties consciousness to integrated information, and not to criticality as such (Albantakis and others, 2023); integrated information is the measure of how far a system's power to cause and to be caused upon itself cannot be reduced to the power of its parts. Work by other researchers joins integrated information and criticality. In a model of the human brain network, Hyoungkyu Kim and UnCheol Lee found that "maximal criticality coincided with maximal" integrated information. Kim and Lee estimated integrated information by a surrogate measure, a stand-in quantity that approximates integrated information. In recordings of the brain, Kim and Lee found that "The conscious resting state showed the largest" of both quantities, criticality and integrated information (Kim and Lee, 2019).

**Where argued.** *The Basis of Physics*, Essay 19, Section V; *The Last Turtle*, Chapter 15, Section VIII; *Causality Without Determinism*, Chapter 5, Section IX; the objection to the claim, and the answer to the objection, in *Objections from Physics, Answered*, Chapter 52.

**Measured.** John Beggs and Dietmar Plenz found in 2003 that activity in cortical circuits comes in cascades, neuronal avalanches, whose sizes follow a power law, the signature of a critical regime. Jonathan Touboul and Alain Destexhe answered in 2010 that "power-law scaling may be a generic property of thresholded stochastic processes" and that it "does not constitute a proof of self-organized criticality". In 2022 Daniel Toker and colleagues reported, from recordings in people and animals, that "during conscious states, the electrodynamics of the cortex are poised near a critical point", and that unconsciousness under anesthesia and in generalized seizures goes with "a transition of low-frequency cortical electric oscillations away from this critical point". The measurements made so far are measurements of interest, and the measurements agree with the statement that the brain operates near criticality.

**What decides it.** In *Objections from Physics, Answered*, Chapter 52, I state what kind of question the claim about criticality raises: "the regime in which the cortex operates is a question of measurement, and its answer leaves the triple as it is". A measurement decides the claim if it tells a critical regime apart from power laws made by noise with no criticality behind them, and Touboul and Destexhe drew that distinction. The bound triple does not rest on whether the cortex operates in a critical regime: the argument for the bound triple "needs no particular biological mechanism and no sustained entanglement in the brain" (*Causality Without Determinism*, Chapter 5, Section IX).

**The statement of the relation essay**

The relation essay places integrated information where the books place criticality: "Integrated information stands where criticality stands. High integration of a system's causes and effects upon itself is a physical circumstance under which acts of comparison gather into one stance, and a system lacking it has no single place where its choices gather". In the collection, a stance is the standpoint from which an act of comparison proceeds. The relation essay makes this statement; the books do not argue the statement, and the sealed record does not carry the statement. In the essay I say that integrated information measures a condition under which a system can have one place where the choices of that system gather, and that integrated information does not measure the experience itself. In the essay I present that statement about what integrated information measures as a placing of the measure, and not as a prediction, and in this record I do not turn the statement into a prediction. The essay's statement has a nearest measured counterpart: the perturbational complexity index of Adenauer Casali, Tononi, Massimini and colleagues, a measure of how complex the brain's response is to a pulse of magnetic stimulation. In 2013 that index "reliably discriminated the level of consciousness in single individuals during wakefulness, sleep, and anesthesia". A new step would be needed to read the essay's sentence as a statement about the sleeping or anesthet-

ized brain, and the books bear on that step: in *What Cannot Be*, Chapter 2, I write that "the laws of a self are laws of persistence, like the law that the self who wakes is the self who fell asleep". This record does not read the essay's sentence that way.

## V. Where No Measurement Decides

A claim can be tested only where the outcome of a comparison can be objective. In *Physics Is Not Math*, Chapter 19, Summary, I state the condition: "A test applies where the outcome of a comparison can be objective: comparable by many, consistent across them, and able to surprise". The differences set out below concern either the subjective or what a rule is. Of the subjective I write: "What is subjective is defined by what cannot be compared, so no third-person observation reaches it" (*Objections from Physics, Answered*, Chapter 52). So falsification (the refutation of a claim by an observation) does not apply to these differences, and the books say so of their own claims of this kind: "That subjectivity is, at its foundation, continuity with asymmetry is a claim of the framework, not a result of any experiment" (*What Cannot Be*, Chapter 21). A claim of this kind is judged by its argument. The philosopher Karl Popper's criterion of falsifiability is a criterion of demarcation for empirical science, and as I read that criterion in *The Ground of Objection*, entry T1.10, "A system placed outside empirical science by his criterion has not been convicted of anything by him".

### What experience is

Tononi's account identifies an experience with the cause-effect structure that a system's maximally irreducible core specifies, and it identifies the amount of an experience with integrated information (Albantakis and others, 2023). The maximally irreducible core is the part of a system whose power to cause and to be caused upon itself is least reducible to the power of its parts, and the cause-effect structure is the full structure of causes and effects that the core specifies. The collection holds that con-

sciousness is the bound triple of the arrow of time, hard randomness and the subjective, taken as one act and held in the act. Hard randomness is an outcome that no prior specification fixes, however complete; described from inside, hard randomness is choice. The collection also holds that a quantity computed from a system's structure, laid out from outside, belongs to the objective character, and that the Incommensuration Theorem keeps the objective character apart from the subjective (*Causality Without Determinism*, Chapter 5, Section III; *The Modern Engagement*, Chapter 7, Sections V and VII). The Incommensuration Theorem states that symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison, and that neither can asymmetry and discontinuity. Kind of claim: a description of what a thing is, which Tononi makes from outside and the collection makes from within the act. A surveyed claim is a claim established from a vantage that holds many cases in view at once, and a performed claim is a claim established by what happens in the act of engaging it. In the relation essay I find that Tononi's identity fails at one step: the step where a number computed from the system's structure, as laid out from outside (a surveyed claim), is said to be the experience held in the act (a performed claim).

**Experience in a wholly determined system**

Consider a network of logic gates whose every next state follows from its present state by rule. On Tononi's account such a network can have high integrated information, and a network with high integrated information has experience. In 2014 the computer scientist Scott Aaronson pressed the case of large networks of gates wired as expander graphs (a pattern of wiring in which every small group of gates connects to many others), and Tononi accepted that such networks have experience and extended that consequence to a plain two-dimensional grid of such gates. The collection holds that a rule with no hard randomness has no arrow of time and no subjective, so that "Classical computation, however intricately organized, cannot be what consciousness is" (*Causality Without Determinism*, Chapter

5, Section VI). Kind of claim: a claim of logical form, about what a rule is, and a reader checks a claim of that form step by step, by following its logical structure. No measurement of a grid decides the claim, since "A third-person description of behavior is the one description that cannot show an inside, for a person or for a program" (Chapter 5, Section IX).

A superdeterministic completion of quantum mechanics would be a deterministic theory beneath quantum mechanics in which the settings chosen for a measurement are fixed together with what is measured. The sealed record registers the physical side of the difference over determined systems, and carries that physical side as Prediction 28:

> No superdeterministic completion of quantum mechanics will be found, and no world is purely and completely deterministic. Some asymmetry of time must exist in the laws, and no process at any scale is perfectly reversible; a reversal of evolution, by an inverse in a formalism or by a pulse in a laboratory, does not remove a finding from the order of findings. These are exclusions that the structure of comparison makes; the outcome of a search for departures from the quantum predictions bears on Prediction 25 and not on this one.

Registered on 1 November 2026 as Prediction 28 of The Registered Predictions of Physics from Comparison. Where argued, as the sealed record gives it: *The Basis of Physics*, Essays 9 and 11; *Measurement*, Chapter 14, Sections II and III; *Why Time Travel Is Not a Concept*, Chapter 5, Sections III to V. So a physical grid of gates is never perfectly deterministic, since no world is purely and completely deterministic, and in the relation essay I grant a physical grid what its interactions have, "something real and simple". The difference between the two accounts concerns the rule from which integrated information is computed, and that rule has no inside, because the rule is fixed. Integrated Information Theory makes no claim about whether the world is deterministic, so Prediction 28 is not a prediction on which the two accounts differ.

**What fixes the quality of an experience**

On Tononi's account, the quality of an experience, what the experience is like, is fully specified by the structure of distinctions and relations that the theory computes. The collection holds that its axioms "predict the structure of consciousness, not the content of any particular experience, so that qualia are not derived from them" (*The Modern Engagement*, Chapter 7, Section XV). Qualia are the qualities of experiences. The collection also holds that a structure of distinctions, held in view as a whole, is the laid-out record of the verdicts that acts of comparison return. Kind of claim: a description of what a thing is.

**What the grades of experience are grades of**

Both accounts place something of mind at every scale. For Tononi the grades of experience are amounts of integrated information, and a photodiode, a sensor of light, linked to a one-bit memory "can have a modicum of experience" (Tononi and Koch, 2015). For the collection the grades are degrees of interaction, "whose degree and kind correlate with the richness and structure of the interaction", and in the richest interactions the choices made are held together by one self that persists (*The Ground of Objection*, entry T3.19). In the same entry I say what the collection does not supply: "The correlation between richness of interaction and degree of consciousness is asserted and is not derived, and the system does not supply a measure of richness or a function from one to the other". In the relation essay I read integrated information as a candidate for that measure of richness, and not as the experience that integrated information measures. Kind of claim: a description of what a thing is.

**Where the two agree, on claims of the same kind**

The two accounts agree that a network which only passes signals forward, a feedforward network, has no consciousness, and that a program as such has no consciousness, since what counts is the physical process and never the program that the process runs (*Causality Without Determinism*, Chapter

5, Section VII). The two accounts also agree that no test of behavior can show an inside, that a being physically identical to a person cannot lack experience, and that a different system matching a person's behavior can lack experience. And the two accounts agree that a science of consciousness begins from experience itself, and that the first axiom of that science, "Experience exists: there is something", is a performed claim. These agreements are claims of the same kind as the differences set out above, and no measurement decides the agreements either.

## VI. What the Collection Does Not Predict Here

The sealed record lists what the books do not predict in its Section IX, "What the Books Do Not Predict", and none of the items listed there bears on Tononi's account: the items concern the measured inputs of physics, cosmology, the kinds of particle, the size of the asymmetry of time, gravitation below the Planck curvature, black holes and travel within the light cone. The books also make no statement about which regions of the brain, or which patterns of their activity, go with conscious perception.

## VII. The Record at Its Date

| Entry | The collection | Tononi | Measured | Standing |
|---|---|---|---|---|
| Section II | No statement about regions or patterns of brain activity | Posterior hot zone; sustained synchronization in posterior cortex | Adversarial collaboration, 2025: content in visual, ventrotemporal and inferior frontal cortex; no sustained synchronization within the posterior cortex | No entry: no measurement separates the accounts |

| Entry | The collection | Tononi | Measured | Standing |
|---|---|---|---|---|
| Tononi 1. The brain operates near criticality | Near criticality, the circumstance under which the bound triple is expressed in us (books; not sealed) | Consciousness goes with integrated information, not criticality as such | Beggs and Plenz 2003; Touboul and Destexhe 2010; Toker and colleagues 2022 | Measurements agree with the collection's statement as far as tested (measurements of interest); Tononi's account makes no prediction here |
| The statement of the relation essay | Integration is the circumstance under which acts of comparison gather into one stance (essay only) | The cause-effect structure is the experience; integrated information is its amount | Perturbational complexity index, 2013, as nearest counterpart | Not a prediction; outside the sealed record |

## Summary

The proponents of Integrated Information Theory have stated in advance where in the brain conscious perception will be found, and they have put those statements to a preregistered test. The test of 2025 bore out some of those statements and went against the theory's prediction of sustained synchronization in the posterior cortex. The collection makes no statement about regions or patterns of brain activity, and the sealed record holds predictions of physics, on which Integrated Information Theory makes no prediction. So no measurement separates the two accounts, and Prediction 28, the one sealed prediction that touches the difference over determined systems, is not a prediction on which the two accounts differ. One statement of the books bears on the brain and can be measured: the state-

ment that the brain operates near criticality. The books argue that the brain's poise near criticality is the circumstance under which consciousness is expressed in us, the sealed record does not carry the statement, and the statement agrees with the measurements made so far. The true differences between the two accounts are claims of a kind that no experiment reaches, and they are judged by their arguments: the differences on what experience is, on whether a wholly determined system has experience, on what fixes the quality of an experience, and on what the grades of experience are grades of. The agreements are judged by their arguments too: the agreements on feedforward networks, on programs, on tests of behavior and on the starting point of the science of consciousness.

**Key Concepts**

- Tononi's theory states in advance where conscious perception will be found, and its proponents put the theory to a preregistered test in 2025.
- The collection makes no statement about brain regions, and the sealed record holds predictions of physics only, so no measurement separates the two accounts.
- The brain operates near criticality: the books argue that the brain's poise near criticality is the circumstance under which consciousness is expressed in us, the sealed record does not carry the statement, and the statement agrees with the measurements so far.
- No experiment reaches the claims about what experience is, whether a determined rule has an inside, what fixes the quality of an experience, and what the grades of experience are grades of, so those claims are judged by their arguments.
- Prediction 28 registers that no world is perfectly deterministic; the difference over determined systems concerns the rule from which integrated information is computed, and not the physical grid of gates.
- Both accounts deny consciousness to feedforward networks and to programs as such, and both hold that no test of behavior can show an inside.

## Terms

**Adversarial collaboration.** A test in which the proponents of rival theories agree beforehand on the experiment, each theory's predictions and how the results will be read.

**Bound triple.** The arrow of time, hard randomness and the subjective: distinct, inseparable and not interchangeable; taken as one act, consciousness.

**Criticality.** The poise of a system between order and disorder, in which small disturbances can cascade to any size.

**Feedforward network.** A network whose signals pass only from input toward output, with no part acting back on another.

**Hard randomness.** An outcome that no prior specification fixes, however complete; described from inside, choice.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The Incommensuration Theorem is a structural fact about the nature of knowing.

**Integrated information.** In Integrated Information Theory, the measure of how far a system's power to cause and to be caused upon itself cannot be reduced to that of its parts.

**Measurement of interest.** In the sealed record, a measurement that differs from a prediction by less than the rule of decision requires.

**Neuronal avalanche.** A cascade of activity in a network of nerve cells; sizes that follow a power law are read as a sign of criticality.

**Performed and surveyed claims.** A performed claim is established by what happens in the act of engaging it; a surveyed claim is established from a vantage that holds many cases in view at once.

**Perturbational complexity index.** A measure of how complex the brain's response is to a pulse of magnetic stimulation, built from the ideas of Integrated Information Theory.

**Posterior hot zone.** The region of the back of the cortex, including sensory areas, where Koch, Massimini, Boly and Tononi placed the correlates of consciousness.

**Rule of decision.** The rule of the registered predictions: a result counts when it is established at five standard deviations by at least two independent kinds of measurement.

**Sealed record.** *The Registered Predictions of Physics from Comparison; A Dated Record, 1 November 2026*, fixed at its date and not revised.

**Superdeterministic completion.** A deterministic theory beneath quantum mechanics in which the settings chosen for a measurement are fixed together with what is measured.

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Appendix G

# The Registered Predictions Beside Karl Friston

*A Dated Record, 4 November 2026*

Date of record: 4 November 2026. This record is fixed at its date of 4 November 2026 and is not revised, and a later report will carry a date of its own. This record sets the predictions of physics from comparison, the physics of the Immanent Metaphysics, beside the predictions of the neuroscientist Karl Friston. This record draws on two sources. The first source is *The Registered Predictions of Physics from Comparison; A Dated Record, 1 November 2026* (DOI https://doi.org/10.67291/RQQS3025), which is not revised; I call that dated record the sealed record. The second source is the relation essay *The Boundary and the Act; Karl Friston's Free Energy Principle and Physics from Comparison*, the chapter of this volume that sets Friston's account beside physics from comparison.

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## Abstract

The neuroscientist Karl Friston and the physics collection of the Immanent Metaphysics agree on where a test applies. In this record, the collection is the set of books in which I set out physics from comparison. The free energy principle is Friston's statement that anything which persists as a thing behaves as if it keeps its variational free energy low, and so can be read as inferring the causes of its sensations. Variational free energy is a quantity that a system can compute and that is never less than the surprise of a sensation, that is, the improbability of the sensation under the system's model. Friston and his colleagues state that the principle "is not falsifiable as a mathematical statement", and the collection's account of

testing places the principle exactly where they place it: a mathematical statement is checked by proof, and an experiment can test every claim that applies the principle to a particular system. The sealed record of 1 November 2026 holds predictions of physics, and one of those predictions bears on Friston's account: Prediction 25, that the statistics of quantum theory hold. Friston's monograph of 2019 presents its Bayesian mechanics, the mechanics that the monograph builds from probability and inference, as compatible with quantum mechanics, and the monograph names no departure from the statistics of quantum theory. So the two accounts agree on Prediction 25, and the measurements made so far agree with both accounts. No measurement named in the relation essay or in the books separates the two accounts, and the relation essay states no prediction of its own. A process theory is a theory that realizes the free energy principle in a particular kind of system, and predictive coding is one of the process theories that realize the principle in brains. The process theories make predictions that experiments in neuroscience test. The collection makes no claim about which mechanisms carry out comparing, so the outcomes of those experiments bear on the process theories and not on the collection. Where the two accounts part, they part on what the boundary of a self is, on whether a computation that minimizes free energy is the act it models, on decision and choice, and on whether probability or comparison comes first. These differences are of a kind that no experiment reaches, which means that no experiment can test a claim of that kind, and this record names each difference together with the kind of claim that the difference is.

## I. What This Record Is

This record sets two accounts side by side. One account is physics from comparison, whose predictions were gathered and sealed on 1 November 2026. The other account is that of Karl Friston, a neuroscientist at University College London. Friston set out the free energy principle in 2006, with James Kilner and Lee Harrison, as an account of the brain. In 2010 he

offered the principle as a candidate for a unified theory of brain function, and in a monograph of 2019 he extended the principle to "every 'thing' that can be distinguished from other things in a statistical sense". In 2023 Friston, Lancelot Da Costa and their colleagues published a statement of the principle in which they compare the free energy principle to Hamilton's principle of least action, a principle of classical mechanics. In the same statement they write that "it is not a falsifiable theory about the way 'things' behave".

The collection's account rests on the Incommensuration Theorem: symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity. The Incommensuration Theorem is a structural fact about the nature of knowing. I formulated the first axiom of the Immanent Metaphysics in or before 1991, and I formulated the Incommensuration Theorem and the ethics of the Immanent Metaphysics in 1996; I did most of my work in physics in 1997 and 1998. *An Immanent Metaphysics*, published in 2001, states the theorem in aphorism 1.43-2 and the three axioms in aphorism 1.3-1.

The rule of decision that this record uses, the rule that says when a result counts, is the sealed record's own: "A result counts when it is established at five standard deviations by at least two independent kinds of measurement. A measurement that differs from a prediction by less is a measurement of interest, and the record reports it as such". This record quotes each prediction of the collection from the sealed record, with the prediction's number, and names at chapter and section a book in which that prediction is argued. The relation essay states no prediction that the books do not argue, so no entry in this record rests on the relation essay alone.

## II. Where the Two Accounts Predict Differently

At this date, 4 November 2026, the two accounts share every measured outcome that the relation essay and the books name, and no measurement is named on which the two accounts predict different results. No named measurement separates Friston's account from the collection's, for three reasons, and each of the three reasons is stated by one account or by the other.

The first reason is Friston's own. As Friston and his colleagues state the free energy principle, the principle is a mathematical statement, and a mathematical statement is checked by whether its conclusions follow from its premises, not by an experiment. In the same sentence they add that the principle "may as well be falsifiable to the extent that its postulates refer to a specific class of empirical phenomena that the principle aims to describe". So Friston and his colleagues draw a line between the principle and its applications to particular phenomena, and the collection draws the same line, as the second reason sets out.

The second reason is the collection's. An experiment can test every claim that applies the principle to a particular system, such as the claim that a population of neurons encodes a given prediction, or the claim that a given behavior lowers a given quantity. In his own program Friston draws the line between the principle and the process theories that realize the principle in particular systems, predictive coding among them, and those process theories are tested in neuroscience. The collection makes no claim about which mechanisms there are. The Ground of Objection, entry T2.24, states that "The system entails that comparison has implementations", and that "A description of neural mechanism is a description within a domain". So whatever a test of a process theory finds, the finding bears on that process theory and not on the collection, and the finding does not tell the two accounts apart.

The third reason concerns the one claim of the relation essay that might seem open to a test: the claim that a computation governed by the free energy principle is not what consciousness is. Causality Without De-

terminism, Chapter 5, Section VI, states that such a computation "may be capable of much else, including behavior that looks, from a third-person vantage, indistinguishable from conscious behavior", and that "The argument is about what a computation is, and so it holds whatever the computation does". So no measurement of behavior bears on the claim, and this record places the claim in Section V, among the differences that no measurement decides.

This section therefore has no entry, and in this record I add no test.

## III. Where the Two Accounts Agree

### Friston 1. The statistics of quantum theory hold

**The collection predicts.** "Repeated measurements on identically prepared systems settle to the weights of the Born rule, in every sector and on the full space, including in the tests proposed for superdeterminism, which look for departures from those weights. The interference among three paths has no term that the pairs of paths do not account for. Tests of the CHSH inequality reach $2\sqrt{2}$ and go no further, and stay at 2 or below whenever either party's two observables commute. Experiments with independent sources find the complex, not the real, composition of independent systems". Registered on 1 November 2026 as Prediction 25 of *The Registered Predictions of Physics from Comparison*. The Born rule is the rule that gives the probability of each outcome of a quantum measurement from the state prepared. Superdeterminism is a deterministic completion of quantum mechanics in which the settings of an experiment are fixed together with the states of what is measured. The CHSH inequality is a form of Bell's inequality for two parties with two settings each: no account with predetermined local answers exceeds 2, and quantum theory reaches $2\sqrt{2}$.

**Friston predicts.** Friston's account predicts no departure from the statistics of quantum theory. His monograph of 2019 recovers quantum mechanics "via the Schrodinger equation" as the monograph's description of

small things, and it recovers quantum mechanics from the same statistical decomposition that picks out a thing. The monograph states that "The ensuing Bayesian mechanics is compatible with quantum, statistical and classical mechanics" (Friston 2019, abstract). The monograph names no measurement at which the weights of the Born rule would fail.

**Where argued.** The Quantum Passage, Chapters 5, 7 and 8, and Appendix B; The Unquantized Arena, Chapter 13, Section VII.

**Measured.** "Three-slit experiments find the third term consistent with zero (Sinha and others 2010); network experiments in 2022 found the complex composition (Chen and others; Li and others)". The sealed record gives the standing as "agrees". No later measurement bearing on it was found between 1 and 4 November 2026.

**What decides it.** Under the rule of decision, any one of four results would decide this entry: a departure from the weights of the Born rule, a term of interference among three paths that the pairs do not account for, a value of the CHSH inequality above $2\sqrt{2}$, or a real composition of independent systems. Any of the four results would bear on both accounts alike, so none of the four results would separate the two accounts. The two accounts part only on how the statistics are reached, which Section V sets out.

## IV. Predictions Stated Only in the Relation Essay

The relation essay states no prediction that the books do not argue and the sealed record does not carry, so this section has no entry.

## V. Where No Measurement Decides

Falsification is the showing that a claim is false by a test. Falsification is a tool that applies where its object is the outcome of a comparison that others can repeat. Physics Is Not Math, Chapter 19, Section III, gives the reason: "A test is a comparison of outcomes, and it can settle something only

when its outcome can be compared: by another person, at another time, along another route", and so "a test applies exactly where the outcome of a comparison can be objective, and nowhere else". Each difference set out below is one of three kinds of claim: a claim of logical form, a description of what a thing is, or a claim about the act of knowing. None of the differences is an outcome that another person reads off an instrument, so falsification does not apply to any of them. Each difference is settled by proof, or by what happens in the act of engaging the claim. Friston places his own principle on the same side of that line, among the claims to which falsification does not apply, and the collection agrees with him that the principle belongs there.

**What kind of claim each foundation is**

*A claim of logical form.* Both accounts place their foundations outside the reach of a test, and both say so openly. The two accounts differ on why their foundations are outside that reach. In the terms of Physics Is Not Math, Chapter 9, Section III, the free energy principle is a surveyed claim: it is "established from a vantage that holds many cases in view at once", and it holds of every model that meets its conditions. The Incommensuration Theorem is a performed claim: it is "established by what happens in the act of engaging it, including the act of trying to deny it" (the same section). The Ground of Objection, entry T1.10, accepts the philosopher Karl Popper's criterion, that a claim belongs to empirical science only if some observation could show the claim to be false, as a demarcation of empirical science, and places the collection's foundation outside empirical science "without embarrassment". So the principle is outside the reach of a test because the principle is mathematics, while the theorem is outside the reach of a test because every test is an instance of the theorem.

### What the boundary of a self is

*A description of what a thing is.* Both accounts hold that a thing is set apart from its world by a boundary across which the thing interacts, and that the thing is never sealed off from its world and never dissolved into it. Causality Without Determinism, Chapter 6, Section VI, says of the self that "The degree of its interaction is never zero (it is always engaged with something) and never infinite". Friston picks out that boundary as a Markov blanket, a statistical partition of a model: a set of states that separates the internal states from the external states, so that each depends on the other only through the blanket. The researchers Jelle Bruineberg, Krzysztof Dołęga, Joe Dewhurst and Manuel Baltieri (2022) distinguish two uses of the blanket: the blanket as a tool of inference within a model ("Pearl blankets"), and the blanket read as the real boundary of a thing ("Friston blankets"). They argue that the step from the first use to the second needs further premises. The collection names that step, in Causality Without Determinism, Chapter 4, Section I: "Compatibility between a model and a body of measurements is not equivalence: many models may be compatible with the same data, and no amount of compatibility can establish that the model is the reality it describes". So the collection identifies the step from a Pearl blanket to a Friston blanket as a step from a model compatible with the measurements to the reality that the model describes. A partition laid out in a model exists, while the boundary of a self is real: the boundary of a self is the place where the self compares, perceives and chooses. So the blanket can describe the boundary of a self exactly, and the blanket cannot be what makes that boundary. No measurement decides whether the blanket is a partition in a model or the real boundary of a self, because every measurement of a living boundary is compatible with both readings of the blanket.

### Whether a computation that minimizes free energy is the act it models

*A description of what a thing is.* Active inference is Friston's name for action that changes the world so that what is sensed fits what is expected. A simulated agent governed by active inference is a program, "a step-by-step procedure whose next state follows necessarily from its current state by a fixed rule" (Causality Without Determinism, Chapter 5, Section II). The collection holds that consciousness is the bound triple of the arrow of time, hard randomness and the subjective, taken as one act (Section III of the same chapter). Hard randomness is an outcome that no prior specification fixes, however complete. The collection also holds that a classical computation lacks all three members of the bound triple, so that "classical computation, however intricately organized, cannot be what consciousness is" (Section VI of the same chapter). Section VI allows that such a computation may behave, from a third-person vantage, in a way that cannot be told apart from conscious behavior. The collection's claim concerns what consciousness is as an act, so no outcome of a test of behavior bears on the claim.

### Decision and choice

*A claim about the act of knowing and choosing.* Expected free energy is the quantity by which active inference ranks courses of action, weighing preferred outcomes and the information an action would gather. In active inference, an agent selects a course of action by ranking a set of courses by their expected free energy and favoring the course whose expected free energy is lowest. Causality Without Determinism, Chapter 6, Section III, defines the two terms: "A decision is a selection from a set of possibilities already defined, made by cutting away the others; if it involves trade-offs, it is a decision. A choice may realize a possibility that was open but not in the set". Selection by expected free energy is decision in this sense. In the collection's account, the random fluctuations in the equations of the free energy principle are the description from outside of what, from inside, is

choice. Chapter 5, Section V of the same book says that hard randomness is "the remainder that no completeness of prior specification closes off", and that hard randomness and choice "are one event described from two positions". The collection excludes a perfectly deterministic world, and the sealed record registers that exclusion as Prediction 28: "No superdeterministic completion of quantum mechanics will be found, and no world is purely and completely deterministic". Friston's account makes no claim either way on whether the world is perfectly deterministic, so Prediction 28 does not separate the two accounts. On decision and choice, the two accounts divide over whether the fluctuation term is the whole of what happens at a choice, and the answer to that question is a claim about the act of choosing.

**Whether probability or comparison comes first**

*A claim of logical form.* Friston's monograph of 2019 begins from probability densities over states and from the conditional independences among those states, and the monograph reads things, their boundaries and their beliefs from that statistical structure. So in Friston's account mathematics comes first, and the collection puts four domains in the opposite order, with mathematics last: metaphysics, physics, computation, mathematics, each presupposing the one before. Physics Is Not Math, Chapter 3, Section VII, states that mathematics "works as if only the objective existed, and as if there were no subjective side at all", and that "What mathematics states leaves the stance out; how mathematics is done keeps the stance in". The collection derives probability rather than assuming it. The Quantum Passage derives the Born rule from the structure of comparison, and the same book holds that what a measurement changes is the laid-out record, "shared and the same for everyone who has the outcome" (Chapter 11, Section V), and not a personal degree of belief. Both accounts predict the same weights of the Born rule (entry Friston 1), so the difference between them is in the order of derivation, and no measurement of the weights bears on that difference.

## VI. What the Collection Does Not Predict Here

Section IX of the sealed record states what the books do not predict, and none of the items of that section bears on Friston's account. The items of Section IX concern the measured inputs of physics, the Hubble constant, the primordial departures, the transition between epochs, the excess of matter over antimatter, the values of the particles, the size of the asymmetry of time, the regime below the Planck curvature, information in black holes, and travel within the light cone. Apart from Section IX, the books make no prediction about which mechanisms an organism uses to compare (The Ground of Objection, entry T2.24), and so the books make no prediction about the findings of neuroscience that test the process theories of the free energy principle.

## VII. The Record at Its Date

| Entry | The collection | Friston | Measured | Standing |
|---|---|---|---|---|
| Friston 1 (Prediction 25) | Born weights in every sector; no third term; CHSH at most $2\sqrt{2}$; complex composition | compatible with quantum mechanics; no departure named | third term consistent with zero (Sinha and others 2010); complex composition (2022) | agrees |

## Summary

Karl Friston and the physics collection agree on where a test applies: Friston's free energy principle, as mathematics, is checked by proof, and its applications to particular systems are claims that experiments can test. Friston's account and the collection also agree on one registered prediction of physics. Friston's account shares Prediction 25 of the sealed record,

that the statistics of quantum theory hold, since his monograph of 2019 presents its Bayesian mechanics as compatible with quantum mechanics and names no departure from those statistics. The measurements made so far agree with both accounts. No measurement named in the relation essay or in the books separates the two accounts, and the essay states no prediction of its own. The collection makes no claim about which mechanisms carry out comparing, so the tests of predictive coding and of the other process theories bear on those theories and not on the collection. The two accounts part on four questions: what kind of claim each foundation is, what the boundary of a self is, whether a computation that minimizes free energy is the act it models, and whether probability or comparison comes first. The two accounts also part on the difference between decision and choice. Each of these differences is a claim of logical form, a description of what a thing is, or a claim about the act of knowing, and no outcome of a measurement bears on any of them.

**Key Concepts**

- Friston states that the free energy principle "is not falsifiable as a mathematical statement"; the collection agrees that a test does not apply to the principle, and that a test does apply to each claim that applies the principle to a particular system.
- Friston's account shares Prediction 25 of the sealed record, that the statistics of quantum theory hold: Friston presents his Bayesian mechanics as compatible with quantum mechanics.
- The collection makes no claim about which mechanisms carry out comparing, so the tests of predictive coding bear on the process theories and not on the collection.
- A Markov blanket describes the boundary of a self exactly and cannot be what makes that boundary, because a partition in a model exists, while the boundary where a self compares is real.
- A computation that minimizes free energy is not what consciousness is, whatever the computation does; no test of behavior bears on that claim.
- Selection by expected free energy is decision. A choice may realize a possibility not in the set, and the fluctuation term in Friston's equations is the description of choice from outside.
- Friston reads physics and mind from probability, while the collection derives probability from comparison.

## Terms

**Active inference.** In Friston's account, action that changes the world so that what is sensed fits what is expected.

**Born rule.** The rule that gives the probability of each outcome of a quantum measurement from the state prepared.

**Bound triple.** The arrow of time, hard randomness and the subjective, distinct, inseparable and not interchangeable; taken as one act, they are consciousness.

**CHSH inequality.** A form of Bell's inequality for two parties with two settings each; no account with predetermined local answers exceeds 2, and quantum theory reaches $2\sqrt{2}$.

**Decision and choice.** A decision selects from a set of possibilities already defined; a choice may realize a possibility open but not in the set.

**Expected free energy.** The quantity by which active inference ranks courses of action, weighing preferred outcomes and the information an action would gather.

**Free energy principle.** Friston's statement that anything which persists, set apart by a Markov blanket, behaves as if it keeps its variational free energy low, and so can be read as inferring the causes of its sensations.

**Hard randomness.** An outcome that no prior specification fixes, however complete; from the position of the one engaged, the same event is choice.

**Incommensuration Theorem.** Symmetry and continuity cannot both be applied, simultaneously and fundamentally, to any event or comparison; and neither can asymmetry and discontinuity.

**Markov blanket.** A set of states that separates internal from external states, so that each depends on the other only through the blanket; Bruineberg and colleagues distinguish its use within a model (Pearl blanket) from its use as the boundary of a thing (Friston blanket).

**Measurement of interest.** In the sealed record, a measurement that differs from a prediction by less than the rule of decision requires.

**Performed and surveyed claims.** A performed claim is established by what happens in the act of engaging it; a surveyed claim is established from a vantage that holds many cases in view at once.

**Process theory.** A theory, such as predictive coding, that realizes the free energy principle in a particular kind of system and makes claims that experiments test.

**Rule of decision.** The rule of the registered predictions: a result counts when it is established at five standard deviations by at least two independent kinds of measurement.

**Superdeterminism.** A deterministic completion of quantum mechanics in which the settings of an experiment are fixed together with the states of what is measured, so that statistical independence fails; the two are fixed together by a prior specification of the world.

**Variational free energy.** A quantity a system can compute that is never less than the surprise of a sensation, its improbability under the system's model.

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